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(PROFESSIONAL PAPER.)

CONCRETE LINING AS APPLIED TO IRRIGATION CANALS.

By Samuel Fortier, *Chief of Irrigation Investigations.*

INTRODUCTION.

An estimate based on the census of 1910 shows that approximately 74,400,000 acre-feet of water is diverted annually from streams, reservoirs, wells, and other sources of supply in the United States for use in irrigation. If this volume were spread over an area the size of the State of New York it would cover it to a depth of over 28 inches. To convey this amount of water, often from distant sources, and distribute it over cultivated lands require a large number of canals with capacities varying from several thousand second-feet to a part of a second-foot, or a few miner's inches. In the United States, irrigation canals are for the most part excavated in earth, and, except in a few cases, a large percentage of the water, estimated at 40 per cent of the amount taken in at the heads of the main canals, is lost by absorption and percolation along the routes. But allowing for water later recovered by lower conduits, the amount that is wholly lost may be reduced to 25 per cent.

The benefits resulting from work in recent years in the lining of canals for preventing transmission losses have been marked.

This publication presents in a summarized form some results of seepage measurements and discusses the subject of lining canals with concrete as one of the best known means of preventing seepage losses. Most of the irrigation canals in this country that have been lined with concrete have been examined and the good and bad features of each noted. Construction methods have likewise been studied. In brief the main object of the entire investigation has been to show, first, the need of an impervious lining and, second, the best practice to follow in construction work of this kind.

Note.—This bulletin treats of the subject of concrete lining for irrigation canals from the standpoints of economy, design, and construction. It is intended for the use of irrigation engineers and the managers and superintendents of irrigation systems.

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UNLINED CANALS.

The census of 1910 showed for that year 81,837 main and lateral ditches, aggregating 125,591 miles in length and having a maximum capacity of 618,097 second-feet. Assuming that not over 4 per cent of the total volume of water used in irrigation was carried in pipes, flumes, and lined canals and deducting all channels having impervious linings, there remained over 120,000 miles of unlined irrigation canals in the West.

Transmission losses in the channels considered herein may be grouped under the headings leakage, evaporation, and seepage. Cheap and faulty structures are a common cause of leakage, but such losses are only a small percentage of the total loss.

A large percentage of the water used to moisten the top layer of soils is evaporated.[1] Water flowing in an open conduit evaporates from the surface an amount dependent upon the temperature of both air and water, the velocity of the wind, and upon other factors. This loss, as in the case of leakage from faulty construction, is so small that it may be neglected without causing appreciable error.

Evaporation data obtained from 37 different stations throughout the various arid States and covering the months of June, July, August, and September give average daily rates in inches for this period as follows: Maximum, 0.34; minimum, 0.18; and mean, 0.26. For practical purposes the loss of water from a canal through evaporation is a negligible quantity.

SEEPAGE LOSSES.

The results of measurements of seepage show that this is the most important source of loss from canals.

As Table I indicates, in many cases full data are not available, particularly as to the character of the materials through which the canals are excavated. The canals measured vary widely in capacity and with one exception are situated in various parts of the arid regions of the United States. About 1,500 miles of separate canal sections are represented in the data collected and considering the character of materials, erosion, age, etc., they cover a wide range of conditions. It must of course be recognized that with measurements taken under such diverse conditions and by the different methods used in collecting these data allowance must be made for probable inaccuracies in the results. It may, and probably does, happen that in cases where the amount of loss or gain is small, the variation may really amount to a gain where it is given as a loss and vice versa depending on the accuracy of the methods used and the care taken in making the measurements for a given canal. However, in collecting these data an effort was

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 248.

made to eliminate all measurements of doubtful accuracy in so far as this could be determined from the records examined.

Two methods of expressing seepage losses in canals are in common use. One method expresses the loss in the percentage of flow of the canal while the other expresses the loss in 24 hours in terms of cubic feet per square foot of wetted area. Opinions differ as to the relative merits of these methods, but each has its advantages. The former gives one a ready grasp of the efficiency of a canal in a general way while the latter permits a more detailed estimate of the loss which may be expected from a given section of a canal when the conditions therein have been carefully studied. However, seepage losses from canals are governed by many variable and interdependent conditions, the combined influence of which it is very difficult, if not altogether impracticable, to reduce to a mathematical formula. The writer is convinced that no refinement of calculation for estimating seepage losses in proposed canals is warranted at this time without considerable data directly applicable to individual conditions, and even when this is obtainable the accuracy of the estimate will largely depend upon the skill as well as upon the experience and judgment of the estimator.

Seepage measurements made by this office together with the greater part of the reliable records obtainable are combined in Table I.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Arizona.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Arizona, Salt River	2	6	79.8 93.3		36.7 37.1	38.0 38.5			4.2 4.5	5.26 4.83
Do	1	12	113.0		36.0	37.1			6.5	5.75
Consolidated, Salt River	3	4	124.6 22.8 53.3		42.3 39.0 40.0	43.5 40.2 41.1			3.5 2.0 2.8	2.81 8.78 5.26
California.										
Callison Slough, Tule River	1	2.5	55.0						7.0	13.00
Tipton Irrigation District, Tule River.	1	10.0	75.5							68.00
Do	1	12.0	48.7							81.00
Fine Ditch, Tule River	2	1.5	21.2 31.9						3.7 7.5	17.00 24.00
Vandalia Ditch, Tule River	2	2.00	16.0							92.00 89.00
	1	1.5	10.2							96.00
Porter Slough, Tule River	1	2.0	97.6							1.60
Do	1	4.0	3.7							46.00
Poplar Ditch, Tule River	3	4.0	35.3 73.3 42.8							25.00 13.00 38.00
Do	1	7.75	73.3							22.00
	1	2.75	26.9							18.00
	1	3.00	21.9							23.00
Pleasant Valley, Tule River	1	4.5	4.9					1.0		50.00
Do	1	5.0	5.6							43.00
South Tule Independent Ditch, Tule River.	2	5.0	7.9 5.6						1.1 .7	14.00 12.50
Modesto, Tuolumne River	1	33.0	260.0						56.1	21.50
Do	1	22.0	532.0							6.60
Do	1	18.0	793.0							3.06
Turlock, Tuolumne River	1	22.0	879.0							4.40
Birch Lateral, Colorado River	1	4.0	17.75							1.00
Do	1	3.0	24.45						.59	2.40
Beach Lateral, Colorado River	1	6.5	7.12						2.75	38.60

measurements.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
0.88	0.80	0.84	0.30 .32		Report W. H. Code, O. E. S. Bul. 104, Sep. No. 2, 1900.	Channel coated with an almost impervious silt deposit.
		.48	.23		do	Do.
2.19	.70	1.40	.33		do	Do.
			.20		do	Do.
			.28		do	Do.
		5.20			Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	
		6.80			do	First use in 5 years. Gopher and squirrel holes in channel bed.
		6.75			do	Do.
16.00	11.30	13.60			do	
46.00	44.50	45.25				
		64.00		See remarks	Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	Channel through sand of the first river bench.
		.80			do	Discharge (97.6) measured at headgate June 1, 1901.
		11.50			do	Discharge (3.7) measured at headgate July 9, 1901.
9.50	3.25	6.33				Measured June 12, 1901, at the head of canal. Measured June 14, 1901, at the head of canal. Measured June 27, 1901, at the head of canal.
		9.46			Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	Measured June 14, 1901, at the head of canal.
		6.55			do	Measured June 29, 1901, 4 miles below head of canal.
		7.66			do	Measured June 29, 1901, at the head of a lateral.
		11.10			do	
		8.60			do	
2.80	2.50	2.65			do	Measured at head. For first 4½ miles bottom width 5 feet, grade 8 feet per mile. The succeeding ½ mile bottom width 6 feet, grade 6 feet per mile.
		.65			Report Frank Adams, O. E. S. Bul. 158, Sep. No. 3, 1904.	See O. E. S. Bul. 158, Sep. No. 3, for losses in individual portions of canal.
		.30			Report Frank Adams, O. E. S. Cir. 108, 1909.	
		.17			do	
		.20			do	
		5.63			Report J. E. Roadhouse, O. E. S. Bul. 158, Sep. No. 3, 1904.	Measured June 16, 1903.
1.41	.80	1.10				Measured June 23, 1903.
		5.90		Sandy, weedy, and flat; 2 miles in embankment.	do	

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
California—Continued.										
Dahlia Lateral, Colorado River	1	9.5	45.40						8.95	19.70
Dogwood Lateral, Colorado River	1	6.0	22.60						5.72	25.30
Holt Lateral, Colorado River	1	5.0	27.3						2.84	10.00
Do	1	3.5	12.9						1.10	8.51
Rose Lateral, Colorado River	1	6.0	36.5						4.54	12.40
Do	1	4.75	24.5						1.22	4.97
Moore Ditch, main canal, Cache Creek.	2	.8	115.6						8.73	7.50
			86.5						5.36	6.20
Do	2	4.0	112.9						4.26	3.80
			116.3						4.62	4.00
Do	2	4.0	126.7						20.9	16.50
			62.6						12.5	20.00
East Fork or Rumsey Ditch, Lateral of Moore Ditch.	2	3.5	108.4						34.4	29.90
			44.1						8.83	20.00
West Fork or Montgomery Ditch, Lateral of Moore Ditch.	1	5.0	65.9						41.4	62.80
Hoy Ditch, Lateral of Moore Ditch	1	3.0	35.42						14.58	41.20
Do	1	.5	20.66						.82	4.00
Stringtown Lane, Lateral of Moore Ditch.	1	2.0	24.69						7.68	31.10
Do	1	.5	17.01						4.60	27.00
South Fork, Lateral of Moore Ditch.	1	1.0	29.93						4.92	16.40
Schoolhouse, Lateral of Moore Ditch.	1	2.0	30.40						15.09	49.70
Capay-Winters, Cache Creek	1	3.0	78.8						36.1	45.80
Do	1	15.5	42.7						7.2	16.80
Do	1	11.5	38.8						12.9	33.30
Central, Sacramento River	1	11.0								37.00
Stony Creek Irrigation Co., Stony Creek.	11	[2] 0.40–8.20	[3] 16.6–80							
San Joaquin and Kings River, San Joaquin River.		5.0	190–239							
Kings River and Fresno, Kings River.	1	3.55	55.7					39.6	4.4	8.00
Do	1	4.75	80.4					8.2	16.5	20.50
Do	1	12.0	133.8					10.1	43.4	32.40

[1] Farmers' laterals foul with weeds, many gopher holes, and diversion weirs out of repair caused many leaks.

measurements—Continued.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	2.07	....	First one-half in slight cut with remainder somewhat silted, especially in last 2 miles.	Report J. E. Roadhouse, O. E. S. Bul. 158, Sep. No. 3, 1904.	Measured June 7, 1903.
......	......	4.22	....	Lateral was in poor condition; deposit of silt inside; levees partially weedy.	.....do	Measured July 8, 1903.
2.43	2.00	2.22	....	Soil varied with strata of silt and clay.	.....do	Measured in 1903.
2.07	1.05	......	....	....	.....do	Do.
......	......	9.40	....	Canal in gravelly creek bed.	Report Samuel Fortier, O. E. S. Bul. 207, 1909.	Measured July 31, 1906.
......	......	7.80	....	....	.....do	Measured Sept. 8, 1906.
......	......	.90	....	Heavy clay loam, puddled by domestic animals.	.....do	Measured Aug. 1, 1906.
......	......	1.00	....	.....do	.....do	Measured July 25, 1906.
......	......	4.10	....	Same section, but much less puddling.	.....do	Measured July 10, 1907.
......	......	5.00	....	.....do	.....do	Measured July 30, 1907.
......	......	8.50	....	....	.....do	Measured July 26, 1906.
......	......	5.70	....	....	.....do	Measured Sept. 8, 1906.
......	......	12.60	....	In an open gravelly soil, apparently former bed of Cache Creek.	.....do	Measured July 19, 1906.
......	......	13.70	....	....	.....do	Measured Aug. 11, 1906.
......	......	8.00	....	....	.....do	Measured July 5, 1906.
......	......	15.50	....	....	.....do	Measured July 17, 1906.[1]
......	......	54.00	....	....	.....do	Measured July 5, 1906.[1]
......	......	16.40	....	....	.....do	Measured July 24, 1906.[1]
......	......	24.80	....	....	.....do	Measured July 5, 1906.[1]
......	......	15.30	....	Canal in old creek bed of wash gravel.	.....do	Measured Aug. 9, 1907.
......	......	1.10	....	Clay loam	.....do	Measured Aug. 9, 1907. Tight diversion weirs.
......	......	2.90	....	.....do	.....do	Measured Aug. 11, 1907, from Winters to State Farm, Davis.
......	......	3.40	....	.....do	.....do	Measured in 1907. Flowing about 100 second-feet at upper end of section; canal designed to carry 8 times this capacity.
8.65	1.06	3.80	....	.....do	.....do	
......	......	.45	....	....	Report Frank Adams, O. E. S. Cir. 108, 1911.	Measured in 1908.
4.32	2.25	3.09	....	Light sandy loam	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898.	Measured in 1882.
			....	Indurated clay hardpan below surface soil.	.....do	Do.
			....	Hardpan bed	.....do	Do.

[2] Average, 4.06. [3] Average, 40.8.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
California—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Fresno, Kings River	1	4.0	60.4	.....	.....	.....	.....	28.0	3.8	6.30
Do	1	7.0	139.1	.....	.....	.....	.....	73.5	5.2	3.70
Do	1	11.25	381.0	.....	.....	.....	.....	146.4	95.5	25.00
Centerville and Kingsburg, Kings River.	1	1.0	251	.....	.....	.....	.....	26.7	52.3	20.80
Do	1	5.5	346	.....	.....	.....	.....	9.1	85.9	24.80
Small ditches	1	1.0	2.41	.....	.....	.....	.....	.....	1.42	59.00
Do	1	.5	1.70	.....	.....	.....	.....	.....	.79	44.00
Lateral of Fresno Canal	1	4.0	5.6	.....	.....	.....	.....	.....	4.38	78.20
Kern County, Kern River	....	General.	.....	.....	.....	.....	.....	.....	.....	.....
Colorado.										
Grand, Grand River	1	4.75	337.0	.....	.....	.....	.....	86.1	[1] 9.60	[1] 2.84
Do	1	2.25	260.5	.....	.....	.....	.....	11.3	8.70	3.34
High line, Grand River	1	5.0	139.6	.....	.....	.....	.....	18.1	5.05	3.62
Do	1	1.25	116.5	.....	.....	.....	.....	8.55	.94	.81
Do	1	6.75	106.98	.....	.....	.....	.....	34.31	1.48	1.38
Do	1	4.75	79.63	.....	.....	.....	.....	20.82	12.9	8.64
Do	1	3.5	55.9	.....	.....	.....	.....	12.42	.99	1.77
Lake, Arkansas River	1	16.0	456.3	.....	.....	.....	.....	249.4	35.6	7.80
Pleasant Valley and Lake, Cache la Poudre.	1	1.30	22.1	.....	.....	.....	.....	.16	4.70	21.30
Do	1	1.31	17.23	.....	.....	.....	.....	.69	5.90	34.2
Do	1	.82	7.17	.....	.....	.....	.....	.....	.88	12.3
Do	1	.72	6.29	.....	.....	.....	.....	.....	.64	10.2
Do	1	.30	6.41	.....	.....	.....	.....	.....	1.87	29.3
Do	1	2.55	13.42	.....	.....	.....	.....	6.19	[1] 4.50	[1] 33.5
Do	1	2.64	13.02	.....	.....	.....	.....	2.82	.25	1.92

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foo tof wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
2.20	0.53	1.43	....	Natural channel; ground water 4 to 10 feet.	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898.	Measured in 1882. Artificial channel of uniform dimensions.
			....	.....do..............	.....do..............	Measured in 1882. Surface soil and subsoils saturated.
			....	.....do..............	.....do..............	Measured in 1882.
20.80	4.50	......	6.0	Porous soil and subsoil.	.....do..............	Do.
			6.0	.....do..............	Also Bul. 48, Colo. Expt. Sta. 1898.	Do.
......	......	59.00	1.2–6.4	Sandy loam 5 to 8 feet deep.	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898; also Bul. 48, Colo. Expt. Sta., 1898.	Measured June 14, 1882, on Gould ranch north of Fresno. Average width, 3 feet; shade trees along portion of ditch, and banks overgrown with grass; weir used.
......	......	88.00	1.2–6.4	Sandy loam with ground water at 8 feet below surface.	.....do..............	Measured June 21, 1882. Lateral of main supply canal; about 2 feet wide; weir used.
......	......	19.50	1.2–6.4	....	.....do..............	Measured June 26, 1882. Diverts water from Fresno Canal at point 4 miles east of Fresno. Average width, 8 feet.
......	......	......	.39–2.60	....	....	
......	......	[1].60	....	Heavy clay; all earth.	Report A. P. Stover, O. E. S. Bul. 119, Sep. No. 3, 1901.	31 diversions in this length. Increase thought to come from irrigated lands west of Palisade.[2]
......	......	1.49	....	In shale hills..........	.....do..............	At numerous places small trickling streams could be seen issuing from canal bank.[2]
......	......	.72	....	Earth..............	.....do..............	Water section entirely in excavation; considerable sidehill.
......	......	.65	....	.....do..............	.....do..............	Same as foregoing but mostly along sidehill.
......	......	.21	....	.....do..............	.....do..............	Comparatively level cross slopes.
......	......	.77	....	.....do..............	.....do..............	Comparatively level cross slopes; in excellent condition.
......	......	.51	....	.....do..............	.....do..............	
......	......	.49	....	Sandy loam..........	.....do..............	Receives heavily laden silt waters, flood time only. Canal follows river for 11 miles.
......	......	16.40	....	Gravelly and sandy; near river.	Report L. G. Carpenter, Bul. 48, Colo. Expt. Sta., 1898.	
......	......	26.10	....	.....do..............	.....do..............	
......	......	15.00	....	Stratified slope; rocks inclining.	.....do..............	
......	......	14.10	....	.....do..............	.....do..............	
......	......	......	....	Along outer side ridge near junction of earth and rock.	.....do..............	
......	......	[1]13.20	....	....	.....do..............	Some land irrigated above ditch from Dixon Canyon.
......	......	.73	....	Somewhat gravelly..	.....do..............	Some land irrigated above ditch from Spring Canyon.

[2] Combining these two measurements shows gain greater than loss.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	
Colorado—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
North farm lateral of Rio Grande Canal, Rio Grande.	2	9.0	90.5	0.88	20.7	......	......	64.3	5.3	5.90
			199.5	1.20	26.0	......	......	156.5	12.5	6.30
Lateral 1C, Rio Grande	1	.5	18.8	.72	13.0	......	......	......	[1] 2.38	[1] 12.70
Do	1	3.0	21.2	......	......	......	......	7.56	6.31	29.70
Prairie, Rio Grande	1	3.5	36.4	......	......	......	......	2.33	[1] 1.42	[1] 3.90
Do	1	1.5	35.5	......	......	......	......	1.92	1.80	5.07
Do	1	4.0	31.9	......	......	......	......	2.81	[1] 3.18	[1] 9.97
Do	1	1.0	29.6	......	......	......	......	......	1.80	6.08
Blackmore, Rio Grande	1	2.03	11.54	......	......	......	......	1.16	3.60	31.20
Empire, Rio Grande	1	5.0	125.0	......	......	......	......	5.02	[1] 16.0	[1] 12.80
Lateral 1F, Rio Grande	1	4.0	12.93	......	......	......	......	2.43	1.68	13.00
Do	1	1.0	8.82	......	......	......	......	2.22	[1] 1.24	[1] 14.00
Lateral of North Poudre Land & Canal Co., South Platte River.	....	4.0	4.49	......	......	......	......	......	.80	20.90
Idaho.										
South Side Twin Falls, Snake River.	1	8.0	900	......	......	......	......	......	64.0	7.10
Lateral of South Side Twin Falls, Snake River.	1	2.+	5.05	......	......	......	......	......	.25	4.95
Do	1	1.0	24.8	......	......	......	......	......	5.6	22.60
Howell & Swendson, Lost River	1	4.0	6.9	......	......	......	......	......	1.7	25.00
Frank Uehren, Lost River	1	.5	1.6	......	......	......	......	......	.3	19.00
Bradshaw, Lost River	1	3.0	5.5	......	......	......	......	......	2.8	51.00
Davidson, Lost River	1	12.0	7.4	......	......	......	......	......	4.6	62.00
Mower, Warm Spring Creek	1	3.0	4.1	......	......	......	......	......	.8	20.00
Sharpe No. 1, Lost River	1	1.0	19	......	......	......	......	......	1.0	5.30
West side (No. 22), Lost River	1	3.5	18.7	......	......	......	......	......	2.7	14.50
Upper Harger (part of No. 23), Lost River.	1	4.0	5.8	......	......	......	......	......	1.7	29.30
Do	1	1.0	4.0	......	......	......	......	......	1.0	25.00
Lower Harger (part of No. 23), Lost River.	1	1.0	11.9	......	......	......	......	......	3.6	30.00
Do	1	3.0	8.75	......	......	......	......	......	.7	8.00
Lateral of Upper Harger, Lost River	1	1.0	2.5	......	......	......	......	......	.2	8.00
Darnley (No. 24), Lost River	1	.25	6.9	......	......	......	......	......	.35	5.00
Do	1	4.0	6.9	......	......	......	......	......	2.4	35.00
Pierce-Keogh, Raft River	1	1.0	4.76	......	......	......	......	......	.66	13.90
Do	1	1.0	4.1	......	......	......	......	......	.14	3.40

[1] Gain.

measurements—Continued.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	0.65	0.51	Gravelly soil	Report L. G. Carpenter, Bul. 48, Colo. Expt. Sta., 1898.	Individual measurements show variations of 8.47 per cent gain to 8.95 per cent loss.
......	......	.70	.73	do	do	Individual measurements show variations of 8.77 per cent gain to 12.18 per cent loss.
......	......	[1]25.30			do	Measured Aug. 2, 1897. Lateral of Rio Grande Canal system.
......	......	9.92				
......	......	[1]1.11			do	Measured July 13, 1897.[2]
......	......	3.38			do	Do.[2]
......	......	[1]2.49			do	Measured July 14, 1897.[2]
......	......	6.08			do	Do.[2]
......	......	15.36			do	Measured June 17, 1897.
......	......	[1]2.56			do	Measured June 11, 1897.
......	......	3.25			do	Measured Aug. 4, 1897. Individual measurements show variations of 5.07 to 0.24 per cent per mile.
......	......	[1]14.00			do	Measured Aug. 4, 1897. Lateral 1F part of Rio Grande Canal system.
......	......	5.23		Mostly clay	do	Measured 1893-1894. Average for two seasons' consecutive run.
......	......	.89		Deep soil	Report H. G. Raschbacher, O. E. S. Cir. 65, 1905.	
......	......	2.47		Silted	do	Usual grade.
......	......	22.60			do	Double usual grade. High velocity prevented silting. This measurement and preceding on different laterals.
......	......	6.25		Gravel	Report A. E. Wright, O. E. S. Cir. 58, 1903.	Grade excessive.
......	......	38.00		do	do	
......	......	17.00		do	do	Grade very excessive.
......	......	5.20		do	do	Grade moderate. Loss mostly in first mile.
......	......	6.50			do	Grade excessive.
......	......	5.30			do	Do.
......	......	4.10			do	
......	......	7.30			do	Carrying only one-fourth capacity; even grade and good alignment.
......	......	25.00			do	Do.
......	......	30.00			do	Even grade and good alignment.
......	......	2.66			do	Do.
......	......	8.00			do	Grade very steep, channel badly eroded in places.
......	......	20.00			do	
......	......	8.75				
......	......	13.90		Very sandy	Report W. F. Bartlett, O. E. S. Bul. 158, Sep. No. 4, 1904.	
......	......	3.40		Lined with soft, fine mud about 0.3 foot deep.		

[2] Measurements taken on abutting sections and given in order.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
South Side Twin Falls, main canal, Snake River.	2	7.79	972	5.0	102.3	......	......	......	91.7	9.40
			1,691	7.9	111.6	......	......	1.3	194.7	11.50
Do	1	......	892	......	......	......	......	1.8	51.0	5.71
Do	1	11.98	839.4	5.3	92.05	......	......	53.7	101.5	12.10
Do	1	8.07	1,448	6.5	96.4	......	......	14.49	121	8.36
Do	1	6.32	1,312	6.6	96.4	......	......	137	93.9	7.15
Do	1	5.35	2,737	7.53	104.0	110.5	3.43	......	93.0	3.40
Do	1	6.070	2,798.0	7.72	107.3	114.30	3.33	......	30.4	1.10
Do	1	2.650	2,857.0	7.73	107.5	114.0	3.42	......	27.0	.95
Do	1	......	2,934.0	......	......	......	......	......	54.0	1.80
Do	1	5.050	3,097.0	8.09	118.0	123.0	3.16	......	148.0	4.80
Do	1	3.350	3,192.0	8.00	123.0	129.0	3.16	......	167.0	5.20
South Side Twin Falls, low line, Snake River.	1	6.40	343.1	3.6	54.85	......	......	37.1	34.8	10.10
Do	1	9.61	332.2	3.3	52.2	......	......	147.6	50.7	15.30
Do	1	6.24	133.9	1.8	37.9	......	......	77.2	22.4	16.70

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.21	1.88	Soil deep and slightly sandy. Numerous rock cuts.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured June 9, 1906, Milner to Dry Creek Reservoir.
......	......	1.48	3.66	....do	....do	Measured Aug. 6, 1906, Milner to Dry Creek Reservoir.
......	......	......	.15	Bottom becoming silted.	....do	Measured June 11, 1906, Dry Creek Reservoir only.
......	......	1.01	1.50	Mostly soil; few rock cuts.	....do	Measured June 12, 1906, Dry Creek Reservoir to within 3¼ miles of end of canal.
......	......	1.03	2.54	Mostly soil; few rock cuts near lower end.	....do	Measured Aug. 6, 1906. Includes upper 8.07 miles of preceding measurement; Dry Creek Reservoir to spillway.
......	......	1.13	2.51	......	....do	Measured Aug. 8, 1906, spillway to near end of canal. Backwater condition in lower end of section.
......	......	.60	2.56	Deep uniform clay loam.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911–12.	Measured July 20, 1912; from Low Line Canal to point 5.35 miles above. Good lower bank; comparatively clean uniform cross section and grade; used 7 years.
......	......	.20	.72	....do	....do	Measured July 18, 1912, from "The Point" to 2.7 miles below Dry Creek Reservoir. Good lower bank; clean uniform cross section; used 7 years.
......	......	.40	1.46	....do	....do	Measured July 18, 1912, the first 2.65 miles below Dry Creek Reservoir. Good lower bank; clean uniform cross section; used 7 years.
......	......	......	......	....do	....do	Measured July 15, 1912; Dry Creek Reservoir only.
......	......	.90	3.905	Deep uniform clay loam with some rock cuts.	....do	Measured July 15, 1912. Upper end of section is 3½ miles below Milner. Banks somewhat eroded; upper bank gone in places; numerous pools above upper bank; used 7 years.
......	......	1.60	6.338	Uniform clay loam with numerous rock cuts.	....do	Measured July 14, 1912. Upper end of section is at Milner wagon bridge. Banks badly eroded; numerous pools above upper bank; no surface indication of seepage; used 7 years.
......	......	1.580	1.62	Heavier than along main canal. Some rock cuts.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured June 15, 1907, stations 359 to 697. Waste water (6.8 second-feet) in addition to inflow; first used June, 1905.
......	......	1.590	1.65	....do	....do	Measured June 18, 1907, stations 697 to 1204½. First used, upper part, June, 1905; lower part, April, 1906.
......	......	2.680	1.48	....do	....do	Measured June 19, 1907, stations 697 to 1534.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Idaho—Continued.										
South Side Twin Falls, high line Snake River.	1	12.68	226.5	2.9	48.5	......	......	13.34	35.2	15.50
Do	1	16.94	177.9	2.7	41.15	......	......	41.4	44.4	25.00
Do	1	11.8	92.1	1.9	28.4	......	......	45.4	16.8	18.20
Do	1	2.180	759.6	4.94	53.5	57.00	2.88	......	[1] 4.01	[1] 1.53
Do	1	2.260	783.0	5.07	56.7	61.40	2.70	......	10.35	1.72
Do	1	2.140	788.4	5.48	53.0	58.90	2.74	......	[1] 12.68	[1] 1.61
Do	1	2.060	832.0	5.55	57.0	62.60	2.61	......	11.1	1.33
Do	1	2.940	877.0	5.31	60.0	64.80	2.72	......	20.9	2.38
South Side Twin Falls, farm lateral, Snake River.	1	.490	.073	.13	.9	1.03	.55	......	.017	23.30
Do	1	.700	.205	.14	1.4	1.51	.97	......	.040	19.50
Do	1	.714	.532	.32	1.5	1.87	1.04	......	.068	12.70
Do	1	.740	.545	.28	1.0	1.35	1.82	......	.070	12.80

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.220	0.93	Some gravel and some white lime. See reference.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured July 2, 1907, from end of main canal to Cottonwood Creek.
......	......	1.470	1.05	....	.....do..............	Measured July 3, 1907, Cottonwood Creek to Cedar draw. First season.
......	......	1.540	.82	....	.....do..............	Measured July 6, 1907, Cedar draw to near end of canal. First season.
......	......	[1] .24	[1] .53	Compact gravel for ½ mile on either side of McMullin Creek; compact clay loam in other places.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured July 26, 1912, from 1 mile above McMullin Creek to Cottonwood flume. Banks solid; uniform grade and cross section; porous irrigated land above; used 7 years.
......	......	.76	1.22	Compact gravel mixed with dense clay loam not so gravelly as preceding section.	.....do..............	Measured July 26, 1912, from 1½ miles below Rock Creek to 1 mile above McMullin Creek. Banks solid and well above water line; uniform grade and cross section; used 7 years.
......	......	[1] .75	[1] 1.65	Compact gravel and clay loam, mixed with gravel.	.....do..............	Measured July 26, 1912, from ½ mile above to 1½ miles below Rock Creek crossing. Banks very solid and well made; uniform grade and cross section; porous irrigated land above; used 7 years.
......	......	.65	1.41	Deep uniform clay loam.	.....do..............	Measured July 25, 1912, from station 180+30 to within ½ mile of Rock Creek crossing. Banks well above water line; uniform grade and clean uniform cross section; used 7 years.
......	......	.81	1.79	.....do..............	.....do..............	Measured July 26, 1912, from ½ mile below Low Line Canal to station 180+30. Banks well above water line; uniform grade and clean uniform cross section; used 7 years.
......	......	48.00	.56	Medium clay loam, some surface rock on top of ground.	.....do..............	Measured Sept. 10, 1912, 1 mile south of Twin Falls. Banks irregular; some grass and weeds; used 5 years.
......	......	28.30	.63	Deep medium clay loam.	.....do..............	Measured Sept. 14, 1912, 4 miles northwest of Twin Falls. Irregular cross section; badly eroded; some grass and weeds; used 4 years.
......	......	17.80	.83	Medium clay loam, hardpan near surface.	.....do..............	Measured Sept. 11, 1912, 7 miles southwest of Twin Falls. Irregular cross section; banks eroded; sweet clover in lower half of ditch section.
......	......	17.40	1.15	Deep medium clay loam.	.....do..............	Measured Sept. 13, 1912, 2 miles northeast of Filer. Sodded banks; moss in water; uniform cross section; water in ditch above normal surface of ground; used 4 years.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
South Side Twin Falls, farm lateral, Snake River.	1	0.528	0.802	0.22	1.9	2.11	1.73	......	0.126	15.70
Do	1	.422	.837	.23	1.5	1.72	2.32	......	.030	3.60
Do	1	.573	.871	.28	1.3	1.62	2.35	......	.045	5.20
Do	1	.480	1.12	.29	1.8	2.11	2.04	......	.104	9.30
Do	1	.945	2.03	.34	2.4	2.82	2.31	......	.265	13.10
Do	1	.659	2.22	.38	2.4	2.83	2.40	......	.055	2.50
North Side Twin Falls lateral, Snake River.	1	2.612	14.71	.63	11.1	12.00	1.83	......	3.48	23.60
Do	1	1.936	24.05	.81	20.4	21.38	1.30	......	5.00	20.80
Farm lateral, Snake River	1	.662	1.91	.86	3.0	4.05	.67	......	.37	19.40
Do	1	.498	5.45	.92	3.9	5.53	1.39	......	.96	17.70
Do	1	.584	6.15	.92	4.6	5.83	1.34	......	.46	7.50
Lateral of Burgess Canal, Snake River.	1	.520	8.94	.83	7.5	8.03	1.36	......	.85	9.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	29.80	1.84	Medium clay loam...	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured Sept. 13, 1912, 4 miles southeast of Twin Falls. Regular cross section; somewhat eroded; no weeds; used 5 years.
......	......	8.50	.68	.....do..............	.....do..............	Measured Sept. 12, 1912, 7½ miles southwest of Twin Falls. Clean clover sod on banks; uniform cross section; used 3 years.
......	......	8.90	.79	Deep medium clay loam.	.....do..............	Measured Sept. 9, 1912, 2 miles west of Filer. Clean uniform cross section; used 4 years.
......	......	19.20	1.68	Rather porous clay loam, hardpan at 3 feet.	.....do..............	Measured Sept. 12, 1912, 7 miles southwest of Twin Falls. Uneven cross section; much moss; water near top of bank; used 4 years.
......	......	13.80	1.63	Deep uniform clay loam, hardpan at 2 to 2½ feet.	.....do..............	Measured Sept. 14, 1912, 6½ miles southwest of Twin Falls. Uniform cross section; 1,000 feet new dike; used 5 years.
......	......	3.80	.49	Medium clay loam, hardpan at 2 feet.	.....do..............	Measured Sept. 11, 1912, 6 miles southwest of Twin Falls. Upper part fairly uniform cross section; lower part somewhat irregular, with weeds; used 5 years.
......	......	9.00	1.81	Deep uniform sandy loam.	.....do..............	Measured June 6, 1912, 2 miles east of Wendell. Carrying only half capacity; clean uniform cross section; used 4 years.
......	......	10.70	1.98	Sandy loam.........	.....do..............	Measured June 6, 1912, 1 mile south of Wendell. Clean uniform cross section; no erosion; carrying only one-fourth capacity; used 3 years.
......	......	29.30	2.23	Gravelly, sandy loam	.....do..............	Measured Aug. 26, 1912, 5 miles southwest of Rigby. Partly in dike; fairly uniform cross section; alfalfa, moss and sweet clover growing in channel; used 5 years.
......	......	35.40	5.69	Very gravelly and porous.	.....do..............	Measured Aug. 25, 1912, 4 miles southwest of Rigby. Uniform cross section; heavy growth of weeds and moss in channel; low velocity; used 6 years.
......	......	12.70	2.2	Very gravelly.......	.....do..............	Measured Aug. 25, 1912, 4½ miles southwest of Rigby. Irregular cross section; some weeds and sweet clover growing in channel; used 6 years.
......	......	18.20	3.33	Medium gravelly....	.....do..............	Measured Aug. 24, 1912, 7 miles southwest of Rigby. Uniform cross section some gopher holes in bank used 7 years.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Lateral of Burgess Canal, Snake River.	1	1.255	12.52	1.42	7.2	9.20	1.14	......	1.57	12.50
Do	1	.674	18.54	1.35	8.6	9.88	1.54	......	1.35	7.30
Vance, Snake River	1	3.171	41.07	1.46	8.9	11.25	2.98	......	4.84	11.80
Randall, Snake River	1	2.833	135.7	2.49	17.0	21.00	3.10	......	9.36	6.90
Salmon River project, farm lateral, Salmon River.	1	.399	.145	.16	1.0	1.17	.84	......	.015	10.30
Do	1	.378	.575	.15	1.5	1.62	2.49	......	.033	5.70
Do	1	.519	.987	.27	3.5	3.72	.99	......	.068	6.90
Do	1	.351	1.28	.29	2.0	2.30	2.19	......	.011	.90
Do	1	.554	2.18	.31	3.0	3.30	2.34	......	.049	2.30
Do	1	.576	2.26	.42	2.5	2.98	2.03	......	.099	4.40
Salmon River project, main canal, Salmon River.	1	2.928	78.6	1.29	45.0	46.25	1.30	......	5.88	7.50

measurements—Continued.

Loss per mile. Maximum.	Minimum.	Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	9.90	2.22	Medium gravelly....	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured Aug. 24, 1912, 4½ miles southwest of Rigby. Uniform cross section; partly in dike; weeds and sweet clover growing in ditch; used 7 years.
......	......	10.80	3.32	.....do..............	.....do..............	Measured Aug. 23, 1912, 7 miles southwest of Rigby. Uniform cross section; carrying about one-half capacity; clean channel; uniform velocity; used 6 years.
......	......	3.70	2.28	Gravelly............	.....do..............	Measured Aug. 17, 1912, 4½ miles southwest of Rigby. Irregular grade and cross section; moss and roots in channel; used 8 years.
......	......	2.40	2.58	Sand and gravel.....	.....do..............	Measured Aug. 16, 1912, 6 miles southeast of Rigby. Uniform grade and cross section; growth moss and weeds in channel and on banks; used 8 years.
......	......	25.90	.55	Medium clay loam...	.....do..............	Measured June 20, 1912, 1½ miles east of Hollister. Banks fairly regular; bottom fairly well silted; used 1 year.
......	......	15.20	.88	Shallow clay loam, hardpan at 1½ feet.	.....do..............	Measured June 19, 1912, ½ mile east of Hollister. Irregular cross section; bottom silted in places; other places hardpan exposed; used 1 year.
......	......	13.30	.68	Clay loam underlain with hardpan at 1½ feet.	.....do..............	Measured June 20, 1912, 1¼ miles east of Hollister. Clean, uniform cross section; hardpan exposed; used 2 years.
......	......	2.50	.23	Clay loam...........	.....do..............	Measured June 21, 1912, 2 miles east of Hollister. Clean, uniform cross section; used 2 years.
......	......	4.00	.43	Shallow clay loam...	.....do..............	Measured June 18, 1912, 1½ miles southwest of Hollister. Clean but somewhat irregular cross section; ditch across nonirrigated sagebrush lands; used 1 year.
......	......	7.60	.95	Medium clay loam, hardpan at 2½ feet.	.....do..............	Measured June 19, 1912, 2 miles south of Hollister. Clean, uniform cross section; water 2½ feet below surface, flowing on hardpan; used 2 years.
......	......	2.60	.71	Medium clay loam, underlain with hardpan and gravel beneath.	.....do..............	Measured June 17, 1912, 3 miles southwest of Hollister. Uniform cross section and grade; canal carrying small part of capacity; water flowing on hardpan; used 1 year.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Salmon River project, lateral A, Salmon River.	1	3.138	92.2	1.96	23.3	24.50	1.98	......	3.44	3.70
Salmon River project, coulee in main canal, Salmon River.	1	3.809	192.4	1.72	67.5	68.25	1.65	......	2.30	1.20
Salmon River project, main canal, Salmon River.	1	4.189	206.9	1.84	68.1	68.75	1.62	......	8.41	4.10
Salmon River project, check basin, Salmon River.	1	....	343.9	......	......	......	......	......	34.2	......
Murphy Land & Irrigation Co. farm lateral.	1	.469	.685	.25	1.8	2.30	1.49	......	.030	4.40
Do	1	1.623	1.282	.28	4.3	4.58	1.03	......	.086	6.70
Do	1	5.254	1.454	.34	3.6	3.96	1.94	......	.562	38.60
Murphy Land & Irrigation Co., main canal.	1	4.568	19.3	.97	10.3	11.25	1.83	......	1.81	9.40
Do	1	3.812	21.7	.98	11.2	11.73	1.87	......	2.25	10.40
Farmers' Union, A-B, Boise River	3	1.69	111.1 96.6 124.4	......	......	......	......	......	......	......
Do	1	2.44	99.7	......	......	......	......	......	......	......
Farmers' Union, B-C, Boise River	2	3.30	98.0 125.3	......	......	......	......	......	......	......
Farmers' Union, C-D, Boise River	1	4.40	114.1	......	......	......	......	......	......	......
Settlers, A-B, Boise River	2	1.43	156.5 165.5	......	......	......	......	......	......	......
Settlers, B-C, Boise River	1	1.73	163.4	......	......	......	......	......	......	......
Settlers, C-D, Boise River	1	.95	158.6	......	......	......	......	......	......	......
Settlers, B-D, Boise River	1	2.68	[1] 154.1	......	......	......	......	......	......	......
Caldwell high line, A-B, Boise River.	2	2.25	116.0 96.3	......	......	......	......	......	......	......
Caldwell high line, B-C, Boise River.	2	1.02	113.4 102.0	......	......	......	......	......	......	......

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.20	0.73	Medium clay loam, underlain with limestone shale at 1½ feet.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911–12.	Measured June 15, 1912. Uniform grade and clean cross section; canal carrying only part of capacity; water flowing on limestone shale; used 2 years.
......	......	.30	.15	Rock and clay loam..	.....do...............	Measured June 16, 1912. Coulee or natural water course; well silted greater part of section.
......	......	1.00	.48	Clay loam underlain by hardpan; rock exposed in places.	.....do...............	Measured June 16, 1912, below check basin. Clean, uniform cross section and grade; used 2 years.
......	......	......	1.09	Lava rock covered with clay loam 1 to 3 feet deep.	.....do...............	Measured June 14, 1912. Small lake about 62 acres; rather regular in outline; 1,200 feet of rock cut at outlet; used 2 years.
......	......	9.30	.45	Impervious clay loam.	.....do...............	Measured May 27, 1912. About 10 wooden drops in this ditch; regular cross section; irregular grade; used 2 years.
......	......	4.10	.19	.....do...............	.....do...............	Measured May 27, 1912. Ditch carrying only one-fifth capacity; uniform cross section; no weeds in channel; used 2 years.
......	......	7.30	.442	Varies between impervious clay loam and sandy loam, all underlain with hardpan.	.....do...............	Measured May 26, 1912. Irregular cross section; carrying only small part of capacity; numerous drops; varying grades; used 2 years.
......	......	2.10	.576	Clay loam mixed with gravel.	.....do...............	Measured May 23, 1912. Clean, uniform cross section; mostly side-hill section; well silted; used 3 years.
......	......	2.70	.82	Clay loam..........	.....do...............	Measured May 23, 1912. Clean, uniform cross section; well silted bottom and banks; used 3 years.
......	......	[1].78	[1].57	Clay, silt, and granite wash.	Report F. W. Hanna, in report of Boise Conference of Operating Engineers, U.S.R.S., Boise, Idaho, Nov., 1911.	Bottom.
......	......	[1]1.35	[1].82			
......	......	[1].49	[1].38			
......	......	[1]1.66	[1]1.12	.....do...............	.....do...............	Do.
......	......	[1].27	[1].20	Granite, sand wash, and lake deposit.	.....do...............	Side hill.
......	......	2.09	1.79			
......	......	1.85	1.26	Granite, sand wash, lake deposit, and volcanic ash.	.....do...............	Bench and bottom fill.
......	......	1.18	1.07	Sand and gravel, partly cemented.	.....do...............	Side hill.
......	......	1.29	1.16			
......	......	1.80	1.87	Cemented gravel and sand.	.....do...............	Do.
......	......	2.85	3.12	.....do...............	.....do...............	Bench.
......	......	.42	.44	.....do...............	.....do...............	Side hill and bench.
......	......	1.01	.67	Sand and gravel more or less cemented.	.....do...............	Side hill.
......	......	.95	.58			
......	......	.61	.43	Volcanic ash, clay and cemented gravel.	.....do...............	Bench.
......	......	2.77	1.85			

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Middleton Water Co., A–B, Boise River.	3	1.73 1.99 1.95	101.3 58.4 57.1	.....	.....	.....	.....	.....	.....	.....
Middleton Water Co. and Middleton Mill Co., Boise River.	1	14.91	107.6	.....	.....	.....	.....	.....	.....	.....
Do	1	16.15	96.0	.....	.....	.....	.....	.....	.....	.....
North Mora, A–B, Boise River	1	2.08	9.51	.....	.....	.....	.....	.....	.....	.....
North Mora, C–D, Boise River	4	2.04	4.43	.....	.....	.....	.....	.....	.....	.....
Rawson, A–B, Boise River	1	4.56	38.7	.....	.....	.....	.....	.....	.....	.....
Kuna, A–B, Boise River	1	1.56	29.1	.....	.....	.....	.....	.....	.....	.....
Teed, A–B, Boise River	1	2.00	11.2	.....	.....	.....	.....	.....	.....	.....
Eight-Mile, A–B, Boise River	1	5.69	32.2	.....	.....	.....	.....	.....	.....	.....
Kennedy, A–B, Boise River	1	5.81	20.4	.....	.....	.....	.....	.....	.....	.....
Eureka, A–B, Boise River	1	2.26	24.5	.....	.....	.....	.....	.....	.....	.....
Do	1	2.20	15.3	.....	.....	.....	.....	.....	.....	.....
Eureka (rating flume to C), Boise River.	1	3.96	11.3	.....	.....	.....	.....	.....	.....	.....
Do	1	....	5.06	.....	.....	.....	.....	.....	.....	.....
Ballantine, C–D, Snake River	1	.85	7.47	.....	.....	.....	.....	.....	.....	.....
Boise Valley, A–B, Snake River	3	1.80	35.4 18.6 14.6	.....	.....	.....	.....	.....	.....	.....
Ridenbaugh farm lateral, Snake River.	1	.682	.277	0.21	1.5	1.69	0.74	......	0.083	30.00
Do	1	.379	.364	.28	1.5	1.78	.78	......	.081	22.20
Do	1	1.534	1.219	.40	2.5	2.90	1.16	......	.096	7.90
Portneuf-Marsh Valley, Main Canal, Portneuf River.	1	1.881	43.6	1.44	19.8	20.75	1.50	......	1.35	3.10
Do	1	1.746	45.5	1.58	19.7	20.75	1.43	......	1.90	4.20
Do	1	3.000	50.3	1.71	19.5	20.58	1.44	......	4.80	9.50
Do	1	4.533	59.0	1.83	21.7	22.68	1.37	......	8.70	14.70
Do	1	4.862	73.0	2.12	24.8	25.90	1.25	......	14.00	19.20

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.25	0.83	Clay and silt overlain with wind-blown ash.	Report F. W. Hanna, in report of Boise Conference of Operating Engineers, U. S. R. S., Boise, Idaho, Nov., 1911.	Bottom.
......	......	5.13	2.04			
......	......	3.66	1.42			
......	......	[1] 2.00	[1] 1.31	Gravel, silt, and clay overlain with wind-blown ash.	......do..............	Do.
......	......	[1] 2.09	[1] 1.25	......do..............	......do..............	Do.
......	......	2.52	.23	Hardpan overlain with mud.	......do..............	Bench.
......	......	11.61	.86	......do..............	......do..............	Average; weeds in canal; bench.
......	......	2.29	.52	Mostly mud bottom underlain with hardpan.	......do..............	Bench.
......	......	.60	.17	Hardpan overlain with mud.	......do..............	Do.
......	......	11.96	1.39	......do..............	......do..............	Do.
......	......	2.32	1.18	......do..............	......do..............	Do.
......	......	1.82	.68	......do..............	......do..............	Do.
......	......	[1] 8.36	[1] 2.52	Clay, silt, muck, and sand.	......do..............	Bottom.
......	......	[1]12.40	[1] 2.20	......do..............	......do..............	Do.
......	......	[1] 8.50	[1] 1.46	......do..............	......do..............	Do.
......	......	[1]20.00	[1] 1.84	......do..............	......do..............	Do.
......	......	[1]15.20	[1] 1.96	Granite, sand wash, and silt.	......do..............	Do.
......	......	[1] 2.06	[1] .93	Sand, granite wash, gravel, and silt.	......do..............	Do.
......	......	[1] 7.70	[1] 1.88			
......	......	[1] 5.52	[1] 1.13			
......	......	43.90	1.17	Clay loam mixed with gravel.	Report D. H. Bark, 9th Biennial Report State Engineer, Idaho, 1911–12.	Measured June 27, 1912, 1 mile south of Meridian. Regular cross-section; weeds on bank; first half-section in low di[illegible]e; used 8 years.
......	......	58.80	1.97	Deep and porous medium clay loam.	......do..............	Measured June 26, 1912, 3 miles west of Meridian. Deep uniform cross-section; some weed growth in channel; used 5 years.
......	......	5.10	.35	Impervious clay loam.	......do..............	Measured June 28, 1912, 2 miles west of Meridian. Uniform cross-section; parallels a larger lateral 10 feet away; used 5 years.
......	......	1.60	.57	Deep, uniform, and finely divided clay loam.	......do..............	Measured Aug. 31, 1912, stations 981+72 to 1081+6. Carrying only small part of capacity; clean uniform grade and cross-section; used 1 year.
......	......	2.40	.86	......do..............	......do..............	Measured Aug. 31, 1912, stations 889+49 to 981+72. Balance same as foregoing.
......	......	3.20	1.28	......do..............	......do..............	Measured Aug. 31, 1912, stations 731+19 to 889+49. Balance same as foregoing.
......	......	3.30	1.39	......do..............	......do..............	Measured Aug. 31, 1912, stations 491+84 to 731+19. Balance same as foregoing.
......	......	3.90	1.82	......do..............	......do..............	Measured Aug. 21, 1912, stations 235+11 to 491+84. Balance same as foregoing.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Idaho—Continued.										
Portneuf-Marsh Valley, Lateral C, Portneuf River.	1	.478	24.1	1.37	12.2	13.20	1.41	......	1.11	4.60
Portneuf-Marsh Valley, lateral, Portneuf River.	1	1.309	13.17	.97	9.5	10.10	1.36	......	.94	7.10
Do	1	1.175	3.84	.68	5.4	5.95	1.02	......	.175	4.60
Louisiana.										
Ferre, pump	2	3.08	80.5 78.1	3.32 3.34	....	....	1.31 1.26	....	2.00 1.90	2.48 2.43
Montana.										
Big Ditch, Yellowstone River	1	22.00	254.5	......	......	......	......	......	65.1	25.60
Do	1	33.90	310.8	......	......	......	......	......	47.1	15.16
Do	1	30.40	300.7	......	......	......	......	......	29.1	9.68
Do	1	28.86	382.9	......	......	......	......	......	12.2	3.19
High line, Yellowstone River	1	18.51	75.2	......	......	......	......	......	20.3	27.05
Yellowstone, Yellowstone River	1	7.00	35.6	......	......	......	......	......	6.9	19.35
Italian, Yellowstone River	1	9.62	50.6	......	......	......	......	......	[1] 2.70	[1] 5.33
Canyon Creek, Yellowstone River	1	12.00	59.7	......	......	......	......	......	10.8	18.02
Mill, Yellowstone River	1	8.00	29.33	......	......	......	......	......	1.78	6.07
Flaherty flat, Yellowstone River	1	3.00	21.28	......	......	......	......	......	1.17	5.50
Merrill, Yellowstone River	1	8.25	30.81	......	......	......	......	......	5.26	17.07
West Gallatin Irrigation Co., West Gallatin River.	1	38.75	114.5	......	......	......	......	......	39.1	34.10
Do	1	26.50	93.7	......	......	......	......	......	26.3	28.10
Do	1	23.25	70.1	......	......	......	......	......	18.8	26.80

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	9.60	2.88	Very gravelly........	Report D. H. Bark, 9th Biennial Report State Engineer, Idaho, 1911–12.	Measured Sept. 3, 1912, 2 miles north of Downey. Clean uniform cross-section; water level in ditch about same as ground surface; used 1 year.
......	......	5.40	1.16	Clay loam slightly mixed with gravel.	.....do...............	Measured Sept. 3, 1912, 2 miles north of Downey. Clean uniform cross-section; carrying less than one-fourth capacity; uniform grade; used 1 year.
......	......	3.90	.41	Sandy loam mixed with small amount of gravel.	.....do...............	Measured Sept. 3, 1912, 2 miles north of Downey. Uniform cross-section; carrying very small part of full capacity; used 1 year.
......	......	.81	....	Acadia silt loam and heavy yellow clay.	Report W. B. Gregory, Journal Assn. Eng. Societies, vol. 49, No. 1, July, 1912.	Measured Aug. 7, 1911, from Benoit flume to Lyons Point flume.
......	......	.79				
......	......	1.16	....	6 miles sandy loam; 5 miles heavy clay; remainder light sandy loam.	Report Samuel Fortier, O. E. S. Bul. 172, 1906.	Measured Aug. 9–13, 1900 from Tilden's ranch to Hesper farm.
......	......	.45	....	....	.....do...............	Measured June 10–13, 1902 Received some inflow from High Line Canal and irrigated lands.
......	......	.32	....	....	.....do...............	Measured Aug. 4–6, 1902. Received some inflow from High Line Canal.
......	......	.11	....	....	.....do...............	Measured 1903. Received some inflow from both the High Line and the Yellowstone canals, and irrigated lands.
......	......	1.46	....	....	.....do...............	Measured 1903.
......	......	2.77	....	....	.....do...............	Do.
......	......	[1] 5.52	....	....	.....do...............	Measured 1903. Receives heavy inflow from canals and irrigated lands above it.
......	......	1.50	....	....	.....do...............	Do.
......	......	.76	....	....	.....do...............	Measured 1903. A large increase in this section in third and fourth miles from head due wholly to seepage.
......	......	1.83	....	....	.....do...............	Measured 1903.
......	......	2.07	....	....	.....do...............	Do.
......	......	.88	....	....	.....do...............	Measured July 18–20, 1900. No canals or irrigated lands to affect this section by waste water.
......	......	1.06	....	....	.....do...............	Measured June 24–25, 1902. No canals or irrigated lands to affect this section by waste water.
......	......	1.15	....	....	.....do...............	Measured 1903. No canals or irrigated lands to affect this section by waste water.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Montana—Continued.		*Miles*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Cameron or Kughen, West Gallatin River.	1	7.82	26.5						7.6	28.70
Kleinschmidt, West Gallatin River.	1	17.50	96.1						10.24	10.70
Middle Creek, West Gallatin River.	1	4.0	63.0		8.5	10.1		31.2	12.2	19.40
Republican, Bitter Root River	1	3.6	120.5		11.25	15.12		9.31	34.3	28.50
Oregon.										
Adams (old), Little Klamath Lake.	1	6	16.99					1.37	1.73	10.20
Adams (new), Little Klamath Lake	1	8	18.16						2.28	12.60
Ankeny, Klamath Lake	1	6.5	43.41						7.84	18.10
Pilot Butte, Deschutes River	1	2.07	88.8					1.0	9.4	10.60
Do	1	1.84	78.4					8.0	6.6	8.42
Do	1	3.0	37.8		24			2.2	5.2	13.80
Do	1	1.78	30.4		32			0.0	1.6	5.26
Do	1	5.81	28.8		36			0.0	2.5	8.68
Do	1	2.25	26.4		19			7.9	4.1	15.50
Oregon Central, Deschutes River	1	2.51	56.6		36.3			0.0	17.7	31.30
Do	1	2.18	38.9					0.0	15.9	40.90
Maxwell, Umatilla River	1	1.75	16.3					0.0	3.2	19.60

measurements—Continued.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	3.67	....	....	Report Samuel Fortier, O. E. S. Bul. 172, 1906.	Measured 1903. Some inflow seepage.
......	......	.61	....	....	....do....	Measured 1903. Seepage inflow from creek channels and narrow irrigated valleys.
......	......	4.85	....	....	Report Samuel Fortier, O. E. S. Bul. 104, Sep. No. 4, 1900.	Measured June 27, 1900.
......	......	7.92	....	Gravelly..........	....do....	Measured July 21-23, 1900, from headgate to north line of Grantsdale.
......	......	1.7	....	....	Report F. L. Kent, O. E. S. Bul. 158, Sep. No. 4, 1904.	Measured July 15, 1904, upper end of section 600 feet below Lost River flume. Grade, 1.8 feet per mile.
......	......	1.57	....	....	....do....	Measured July 16, 1904, upper end of section, 300 feet below Lost River flume. Grade, 0.7 foot per mile.
......	......	2.78	....	First mile along a very rocky and in places steep hillside.	....do....	Measured Aug. 20, 1904, upper end of section, 200 feet below power plant. Doubtless heavy loss in first mile.
......	......	5.12	....	Extremely rough....	Report A. P. Stover, O. E. S. Cir. 67.	Measured Sept. 5, 1905. Heavy grade, numerous natural drops. Stations 75+100 to 184+50.
......	......	4.57	....	....do....	....do....	Measured Sept. 5, 1905. Heavy grade, numerous natural drops. Stations 184+50 to 281+40.
......	......	4.59	....	Rough in places, natural channels in places, some silting where grade is light.	....do....	Measured Sept. 8, 1905, stations 71+00 to 228+90.
......	......	2.96	....	....	....do....	Measured Sept. 8, 1905, from stations 228+90 to 322+90.
......	......	1.49	....	Rock cut..........	....do....	Measured Sept. 8, 1905, from stations 322+90 to 630+00. Heavy grade first one-third section; remainder light grade.
......	......	6.90	....	....	....do....	Measured Sept. 8, 1905, from stations 630+00 to 760+00. Channel entirely in cut; grade light.
......	......	12.5	....	Rock cut first 2 miles; remainder in earth, with small rock cuts at intervals.	....do....	Measured Sept. 6, 1905, from station 34+75 to 170+50. Bottom well silted; new channel; dry for some time; porous.
......	......	18.7	....	Earth, with small rock cuts at intervals.	....do....	Measured Sept. 6, 1905, from station 170+50 to 285+50. New channel in good condition; dry for some time; lower end of section well silted.
......	......	11.2	....	Mostly cement gravel and bowlders.	....do....	Measured July 20, 1905, headgate to waste gate No. 2. New channel; only slightly silted; grade uniform.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Oregon—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Maxwell, Umatilla River	1	0.23	13.1	.....	.....	.....	.....	0.0	1.6	12.20
Do	1	1.75	11.5	.....	.....	.....	.....	0.6	5.6	48.70
Do	1	1.50	5.5	.....	.....	.....	.....	0.0	2.4	43.70
Irrigon, Umatilla River	4	8.33	21.6	.....	.....	.....	.....	0.0	15.9	73.60
Do	1	.947	15.6	.....	.....	.....	.....	0.0	3.0	19.20
Do	1	.947	12.6	.....	.....	.....	.....	0.0	1.3	10.30
Do	1	1.022	11.3	.....	.....	.....	.....	.8	2.0	17.70
Do	1	1.042	8.5	.....	.....	.....	.....	0.0	.4	4.70
Do	1	.815	8.1	.....	.....	.....	.....	0.0	.3	3.70
Do	1	1.193	7.8	.....	.....	.....	.....	0.0	2.0	25.60
Do	1	.530	7.1	.....	.....	.....	.....	0.0	.9	12.70
Do	1	.890	6.2	.....	.....	.....	.....	0.0	1.0	16.10
Do	1	.947	5.2	.....	.....	.....	.....	0.0	1.0	19.20
Do	1	.379	4.2	.....	.....	.....	.....	0.0	1.7	40.50
Do	1	8.901	17.7	.....	.....	.....	.....	1.1	6.3	35.60
Bowne, Lost River	1	1	9.9	.....	.....	.....	.....	.....	1.0	10.10
Dunn (lateral), near Ashland	1	2.25	2.21	.....	.....	.....	.....	.....	.32	14.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	53	....	Cement gravel cut...	Report A. P. Stover, O. E. S. Cir. 67.	Measured July 20, 1905, waste gate No. 2 to end of gravel cut.
......	......	27.8	....	Coarse, sandy soil, in some few places well silted.	.....do	Measured July 20, 1905, from end of gravel cut to lateral No. 1. Under comparatively low velocities scouring causes loss through porous lining.
......	......	29.1	....	Much the same as preceding section.	.....do	Measured July 20, 1905, from lateral No. 1 to siphon intake. Toward lower end section quite well silted.
......	......	8.84	....	....	.....do	Measured July 13, 1905, from headgate to station 440. See detailed description in succeeding 10 sections measured.
......	......	20.3	....	1,800 feet flume, 4.8 feet wide, 2 feet deep; remainder coarse, porous gravel and shifting sand.	.....do	Measured Aug. 8, 1905, from headgate to station 50. Loss mostly through portion in coarse, porous gravel; no deposition of silt; cross section irregular; banks of shifting sand.
......	......	10.9	....	Heavy sand and gravel cuts.	.....do	Measured Aug. 8, 1905, from station 50 to station 100. Irregular cross section; no silting.
......	......	17.3	....	Much gravel and loose sand.	.....do	Measured Aug. 8, 1905, from station 100 to station 154. Uniform cross section; steep side hill; silting only at intervals.
......	......	4.5	....	Fine sand and gravel.	.....do	Measured Aug. 8, 1905, from station 154 to station 209. Uniform cross section; well silted.
......	......	4.5	....	Porous gravel, with bottom filled 8 to 10 inches deep with fine sand.	.....do	Measured Aug. 8, 1905, from station 209 to station 252. Uniform cross section; quite well silted.
......	......	21.5	....	Sand, with hardpan at depths of 4 to 8 feet.	.....do	Measured Aug. 8, 1905, from station 252 to station 325. Uniform cross section; part of section well silted.
......	......	23.9	....	Exposed gravel in lower end of section.	.....do	Measured Aug. 9, 1905, from station 325 to station 353. Uniform cross section; bottom well silted.
......	......	18.1	....	Through sand cuts...	.....do	Measured Aug. 9, 1905, from station 353 to station 400. Uniform cross section; fairly well silted.
......	......	20.6	....	Much the same as preceding section.	.....do	Measured Aug. 9, 1905, from station 400 to station 450. The several hundred feet on ridge seeps heavily.
......	......	......	....	Mostly well silted coarse sand.	.....do	Measured Aug. 9, 1905, from station 450 to station 470.
......	......	4.0	....	....	.....do	Measured Sept. 19, 1905. See detailed description in preceding 10 sections measured.
......	......	10.1	....	....	Report F. L. Kent in office manuscript.	Measured 1905. Supplied from pumping plant.
......	......	6.4	....	....	.....do	Measured 1905.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	Total loss in section.
Utah.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Logan and Richmond, Logan River	2	0.549	77.70	......	14.25	19.05	......	......	1.14	1.47
Do	2	.71	71.44	......	14.65	19.18	......	......	2.26	3.16
Do	2	.515	70.71	......	14.05	18.10	......	......	1.89	2.67
Do	2	.306	72.32	......	15.15	19.30	......	......	.34	.47
Do	1	.843	58.69	......	12.30	16.80	......	......	2.72	4.63
Do	6	1.449	64.41–91.59	......	13.20	18.40	......	......	7.40	9.09
Logan, Hyde Park and Smithfield, Logan River.	6	0.244–.947	36.66–52.78	......	......	......	......	......	......	......
Do	7	1.36	37.43–58.57	......	14.20	17.10	......	......	4.89	9.82
Do	1	1.32	48.0	......	......	......	......	......	21.30	44.40
East Jordan, Jordan River	1	2.5	42.46	......	......	......	......	......	6.46	15.30
Bear River main line, Bear River	1	1.5	279.3	......	......	......	......	1.75	14.03	5.02
Do	1	.75	263.6	......	......	......	......	......	5.20	1.97
Do	1	3.25	258.4	......	......	......	......	.75	2.89	1.12
			356.3	......	......	......	......	......	35.79	10.04
			458.6	......	......	......	......	......	70.3	15.30
Do	5	5.5	424.2	......	......	......	......	......	70.7	16.70
			380.4	......	......	......	......	......	59.4	15.60
			298.9	......	......	......	......	......	33.3	11.10
Bear River west line, Bear River	1	3.5	138.6	......	......	......	......	2.93	[1] 1.88	[1] 1.36
Do	1	4.0	137.5	......	......	......	......	6.29	1.84	1.34
Do	1	2.5	129.4	......	......	......	......	17.3	2.14	1.65
Do	1	6.5	110.0	......	......	......	......	62.3	4.47	4.06

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
		2.67			Report George L. Swendsen, O. E. S. Bul. 104, Sep. No. 3, 1900.	Measured 1899. Averages only.
		4.45			do	Do.
		5.20			do	Do.
		1.50			do	Do.
		5.50			do	Do.
		6.27			do	Measured 1900. Average measurements for identical sections.
		3.85			do	Measured 1899. Loss in per cent average for six measurements.
		7.22			do	Measured 1900. Average measurements for identical sections. Measurement July 12 omitted. Steep mountain side.
		33.60			Report Samuel Fortier, Utah Expt. Sta. Bul. 26, 1893.	Measured Aug. 31, 1893. Upper end of section at headgate. All in canyon.
		6.10		Coarse	Report Irrigation Investigations for 1900, O. E. S. Bul. 104.	Measured Aug. 11, 1900, along steep hillside from headgate to power plant.
		3.30		Mostly rock cut, some disintegrated limestone.	Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 25, 1901, from headgate to flume No. 1.
		2.60		Porous side hill along river bottom.	do	Measured June 25, 1901, from flume No. 1 to flume No. 3.
		.34		Heavy compact soapstone formation.	do	Measured June 25, 1901, from flume No. 3 to Corrinne division gates. Along side hill bluffs.
		1.83		See measurements for 1901.	Report J. C. Wheelon, of Utah Sugar Co., office manuscript.	Measured May 28, 1902, from headgate to Corrinne division gates.
		2.79		do	do	Measured June 28, 1902, from headgate to Corrinne division gates.
		3.03		do	do	Measured July 28, 1902, from headgate to Corrinne division gates.
		2.84		do	do	Measured Aug. 26, 1902, from headgate to Corrinne division gates.
		2.03		do	do	Measured Sept. 22, 1902, from headgate to Corrinne division gates.
		1.39			Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 25, 1901, from Corrinne division gates to Malade flume. Entirely in excavation.
		.34			do	Measured June 25, 1901, from Malade flume to bridge No. 13. Entirely in excavation, uniform conditions.
		.66			do	Measured June 25, 1901, from bridge No. 13 to bridge No. 18. Entirely in excavation; uniform conditions.
		.63			do	Measured June 26, 1901, from bridge No. 18 to Roweville.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	Total loss in section.
Utah—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Bear River, west line, Bear River	6	16.5	199.7	.....	.....	.....	.....	.....	20.2	10.10
			245.4	.....	.....	.....	.....	.....	20.0	8.15
			218.0	.....	.....	.....	.....	.....	19.6	9.00
			185.5	.....	.....	.....	.....	.....	12.6	6.80
			151.7	.....	.....	.....	.....	.....	19.3	12.70
			81.6	.....	.....	.....	.....	.....	6.7	8.20
Bear River, Corrinne line, Bear River.	1	8.5	118.9	.....	.....	.....	.....	31.9	7.37	6.20
Do	1	5.5	79.7	.....	.....	.....	.....	28.3	4.53	5.68
Do	1	3.75	55.5	.....	.....	.....	.....	12.13	2.69	4.85
Anderson & Spilsbury, near Toquerville.	1	.75	1.76	.....	.....	.....	.....	.....	.41	23.30
Peter Anderson, near Bellevue	1	7.0	2.93	.....	.....	.....	.....	.....	.35	12.00
Bellevue Town, Bellevue	1	1.5	8.98	.....	.....	.....	.....	.....	.58	6.50
Cottonwood, St. George	1	14.0	7.03	.....	.....	.....	.....	.....	3.17	45.10
Brigham Dalton, Rockville	1	.5	.72	.....	.....	.....	.....	.....	.04	5.60
Davis and Pace, near New Harmony	1	.12	2.29	.....	.....	.....	.....	.....	.18	7.90
Dry field, near New Harmony	1	1.0	2.32	.....	.....	.....	.....	.....	.28	12.10
Flanigan, near Springdale	1	.75	14.5	.....	.....	.....	.....	.....	.86	5.90
Hurricane, near Hurricane	1	4.12	21.84	.....	.....	.....	.....	.....	2.25	10.30
William Jackson, near Toquerville	1	.75	1.2	.....	.....	.....	.....	.....	.02	1.70
La Verkin, near Toquerville	2	.75	13.55	.....	.....	.....	.....	.....	.45	3.30
			7.34	.....	.....	.....	.....	.....	.01	.10
La Verkin field, near Toquerville	1	.5	3.45	.....	.....	.....	.....	.....	.56	16.20
Leeds, near Leeds	1	1.0	9.60	.....	.....	.....	.....	.....	.65	6.80
Daniel Mathews, near Mount Dell	1	.25	1.51	.....	.....	.....	.....	.....	.17	11.20
Mill Race, Virgin	1	.095	.74	.....	.....	.....	.....	.....	.08	10.80
Mount Carmel City, near Mount Carmel.	1	.75	4.45	.....	.....	.....	.....	.....	.02	.50

measurements—Continued.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	0.61	....	....	Report J. C. Wheelon, of Utah Sugar Co., office manuscript.	Measured May 28, 1902, from Corrinne division gates to Roweville.
......	......	.49	....	....	....do....	Measured June 28, 1902, from Corrinne division gates to Roweville.
......	......	.54	....	....	....do....	Measured July 28, 1902, from Corrinne division gates to Roweville.
......	......	.41	....	....	....do....	Measured Aug. 26, 1902, from Corrinne division gates to Roweville.
......	......	.77	....	....	....do....	Measured Sept. 22, 1902, from Corrinne division gates to Roweville.
......	......	.50	....	....	....do....	Measured Oct. 24, 1902, from Corrinne division gates to Roweville.
......	......	.73	....	....	Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 26, 1901, from Corrinne division gates to bridge No. 14.
......	......	1.03	....	....	....do....	Measured June 26, 1901, from bridge No. 14 to Red Flume.
......	......	1.29	....	....	....do....	Measured June 27, 1901, from Red Flume to bridge No. 25.
......	......	31.00	....	¾ sandy loam; ¼ river worn gravel and bowlders 2 inches to 2 feet in diameter.	Records of office State engineer of Utah.	Approximate grade 5 feet per mile.
......	......	1.70	....	5 miles solid rock in ravine; 2 miles black loam.	....do....	700 feet fall.
......	......	4.30	....	⅓ bowlders; ⅔ volcanic soil.	....do....	40 feet fall.
......	......	3.20	....	½ solid sandstone ravines; ⅜ sand and ⅛ black loam.	....do....	700 feet fall.
......	......	11.10	....	Sandy loam....	....do....	4 feet fall.
......	......	66.00	....	Fine gravel and clay.	....do....	1½ feet fall.
......	......	12.10	....	Sand and clay....	....do....	7 feet fall.
......	......	7.90	....	Black loam and gravel.	....do....	5 feet fall.
......	......	2.50	....	Volcanic ledge; gypsum in places.	....do....	20 feet fall.
......	......	2.20	....	Sandy loam....	....do....	5 feet fall.
......	......	4.40	....	Volcanic ledge; gypsum in places.	....do....	5 feet fall. Measured May 10, 1910.
......	......	.18	....	....do....	....do....	5 feet fall. Measured May 26, 1910. Coated with clay since previous measurement.
......	......	32.40	....	Sandy loam....	....do....	5 feet fall.
......	......	6.80	....	Bedded sandstone with strata dipping toward the mountain.	....do....	50 feet fall.
......	......	45.00	....	Sandy loam and gravel.	....do....	2 feet fall.
......	......	......	....	Sandy loam....	....do....	1 foot fall.
......	......	.60	....	Channel coated with clay deposit from floods.	....do....	6 feet fall.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured. Length.	Section measured. Flow at upper end.	Dimensions of canal. Mean depth.	Dimensions of canal. Width of water surface.	Dimensions of canal. Length of wetted perimeter.	Velocity in canal.	Diversions in section.	Total loss in section.	
		Miles.	Sec.-ft.	Ft.	Feet.	Feet.	Feet per sec.	Sec. feet.	Sec. feet.	Per cent.
Utah—Continued.										
North Ash Creek, near Bellevue	1	0.50	1.66						0.17	10.20
Orderville Town, near Orderville	1	.25	4.45						[1] .01	.22
Pace & Prince, near New Harmony	1	.123	1.85						.23	12.40
Henry A. Pace No. 1, near New Harmony.	1	.21	.58						.08	13.80
Rockville South Field, near Rockville	1	.19	3.7						.11	3.00
Joseph Sanders, near Mount Dell	1	.25	1.01						.05	5.00
Santa Clara South Field, near Santa Clara.	1	.40	4.57						.73	16.00
Santa Clara Town, near Santa Clara	1	.25	2.61						.03	1.20
Gottlieb Schmutz No. 1, near New Harmony.	1	.25	.41						.01	2.40
Shones Creek, near Shonesburg	1	.50	1.11						.43	38.70
Spring Ditch, near Toquerville	1	.25	2.52						.71	28.20
St. George and Washington Field, near Washington.	1	4.25	51.98						1.58	3.00
West Field, Toquerville	1	.17	3.84						.06	1.60
Huntington, Huntington	1	1.25	17.72						1.39	7.80
Washington.										
Prosser Falls Irrigation Co., Lateral, Yakima River.	1	.379	.50						.32	64.00
Kennewick, Yakima River	4	9.0	123.0						32.0	26.00
			161.0						30.0	18.60
			148.0						24.0	16.20
			78.6						9.8	12.50
Do	2	2.6	131.0						5.0	3.80
			124.0						4.0	3.20
Do	2	8.6	68.8						10.9	15.80
			91.0						23.0	25.30
Do	1	6.0	120.0						13.0	10.80
Selah-Moxee, Yakima River	2	1.42	53.3						1.8	3.40
			49.8						1.2	2.40
Do	1	2.6	49.8						2.1	4.20
Do	1	1.57	29.0						.2	.70
Sunnyside main line, Yakima River		30.0	636.0					258.0	38.0	6.00
Do		18.0	340.0					171.0	40.0	11.80

[1] Gain.

measurements—Continued.

Loss per mile. Maximum.	Loss per mile. Minimum.	Loss per mile. Mean.	Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	20.00	....	Sandy loam	Records of office State engineer of of Utah.	5 feet fall.
......	......	1.90	....	Channel coated with thick layer of clay.	....do	2 feet fall, ground saturated from recent rains.
......	......	......	....	Gravel and black loam.	....do	1 foot fall.
......	......	66.00	....	....do	....do	2 feet fall.
......	......	15.70	....	Sandy loam	....do	2 feet fall.
......	......	19.80	....	....do	....do	3 feet fall.
......	......	40.00	....	....do	....do	4 feet fall.
......	......	4.60	....	....do	....do	2 feet fall, flowing a much larger stream a few hours before.
......	......	9.80	....	Gravel and black loam.	....do	2 feet fall.
......	......	77.40	....	Sand and gravel	....do	7 feet fall.
......	......	......	....	¾ sandy loam; ¼ river worn gravel and bowlders, 2 inches to 2 feet in diameter	....do	2 feet fall.
......	......	.70	....	Sandy loam	....do	21 feet fall.
......	......	9.20	....	River rocks and sandy loam.	....do	3 feet fall.
......	......	6.30	....	Clay and blue slate rock points.	....do	7 feet fall.
......	......	......	....	Mostly coarse gravel covered with soil 4 to 9 inches deep.	Report O. L. Waller, O. E. S. Bul. 104, 1900.	Measured Oct. 31, 1900.
......	......	2.90	....	....	Report S. O. Jayne, O. E. S. Bul. 188.	Measured Sept. 9, 1904, De Moss's bridge to flume No.1
......	......	2.10	....	....	....do	Measured May 11, 1906, De Moss's bridge to flume No.1
......	......	1.80	....	....	....do	Measured Sept. 27, 1906, De Moss's bridge to flume No.1
......	......	1.40	....	....	....do	Measured Oct. 16, 1906, De Moss's bridge to flume No. 1
......	......	1.50	....	....	....do	Measured Sept. 27, 1906, flume No. 1 to flume No.2.
......	......	1.20	....	....	....do	Do.
......	......	1.80	....	....	....do	Measured Sept. 9, 1904, flume No. 1 to flume No. 3.
......	......	2.90	....	....	....do	Measured May 11, 1906, flume No. 1 to flume No. 3.
......	......	1.80	....	....	....do	Measured Oct. 16, 1906, flume No. 2 to flume No. 3.
......	......	2.40	....	....	....do	Measured July 3, 1906, flume to Butterfield's bridge.
......	......	1.70	....	....	....do	Measured Aug. 21, 1906, flume to Butterfield's bridge.
......	......	1.60	....	Mostly seamy basaltic rock.	....do	Measured Aug. 21, 1906, flume to northeast corner section 21.
......	......	.40	....	....	....do	Measured July 6, 1906, cemetery to Rankin hopyard.
......	......	.20	.48	....	Report J. C. Stevens, Trans. Am. Soc. C. E., vol. 71, p. 339, 1909.	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909. From intake to 30 mile station.
......	......	.65	1.04	....	....do	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909. From 30-mile station to 48-mile station.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec. feet.*	*Sec. feet.*	*Per cent.*
Washington—Continued.										
Sunnyside main line, Yakima River.	....	12.0	129.0	.....	......	......	......	99.0	21.0	16.30
Sunnyside, Snipes Mountain Lateral, Yakima River.	....	9.0	89.0	.....	......	......	......	57.0	12.0	13.50
Wyoming.										
Wheatland No. 2, Laramie River...	2	1.50	89.7	.....	......	......	......	00.0	4.35	4.85
			36.5	.....	......	......	......	0.0	1.46	4.00
Do...	2	2.50	85.3	.....	......	......	......	0.0	4.23	4.96
			35.1	.....	......	......	......	0.0	1.05	2.99
Do...	2	2.40	81.1	.....	......	......	......	0.0	3.06	3.77
			34.0	.....	......	......	......	10.95	[1].27	[1].79
Do...	2	4.40	78.0	.....	......	......	......	25.79	2.78	3.56
			23.3	.....	......	......	......	12.05	[1]2.03	[1].87
Do...	2	1.70	49.4	.....	......	......	......	0.0	.20	.40
			13.3	.....	......	......	......	0.0	1.07	8.04
Do...	2	2.17	49.2	.....	......	......	......	20.88	.48	.97
			12.2	.....	......	......	......	5.64	.19	1.56
Do...	1	2.33	27.9	.....	......	......	......	12.31	.15	.54

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.36	1.65	....	Report J. C. Stevens, Trans. Am. Soc. C. E., vol. 71, p. 339, 1909.	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909. From 48-mile station to 60-mile station.
......	......	1.50	1.24	....	....do............	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909.
......	......	3.23	....	....	Report Clarence T. Johnston, O. E. S. Bul. 104, 1900.	Measured July 9-11, 1900, from station 1 (headgate) to station 2.
......	......	2.67	....	....	....do............	Measured Aug. 20-22, 1900, from station 1 (headgate) to station 2.
......	......	1.98	....	....	....do............	Measured July 9-11,1900, from station 2 to station 3.
......	......	1.20	....	....	....do............	Measured Aug. 20-22, 1900, from station 2 to station 3.
......	......	1.57	....	....	....do............	Measured July 9-11, 1900, from station 3 to station 4.
......	......	1.33	....	....	....do............	Measured Aug. 20-22, 1900, from station 3 to station 4.
......	......	.81	....	....	....do............	Measured July 9-11, 1900, from station 4 to station 5.
......	......	1.20	....	....	....do............	Measured Aug. 20-22, 1900, from station 4 to station 5.
......	......	.24	....	....	....do............	Measured July 9-11, 1900, from station 5 to station 6.
......	......	4.73	....	....	....do............	Measured Aug. 20-22, 1900, from station 5 to station 6.
......	......	.45	....	....	....do............	Measured July 9-11, 1900, from station 6 to station 7.
......	......	.72	....	....	....do............	Measured Aug. 20-22, 1900, from station 6 to station 7.
......	......	.23	....	....	....do............	Measured July 9-11, 1900, from station 7 to station 8.

FACTORS AFFECTING SEEPAGE.

It is not within the scope of this publication to include a detailed discussion of the various factors influencing seepage, but in order to form a reliable estimate of the loss by seepage from a proposed canal, the principal factors should be carefully considered. Briefly these are:

(1) Size and shape of grains and general character of materials.

(2) The gradual deposition of silt.

(3) Depth of water over the wetted perimeter.

(4) The relation which the wetted perimeter of the canal bears to other hydraulic elements.

(5) Velocity of water in canal.

(6) Inflow of seepage water.

(7) Temperature of the soil and the water.

A study of the results of the measurements secured brings out the close relation existing between the unit loss as expressed in percentage of flow and the size of the canal. Three hundred and twenty-three separate and distinct sets of measurements are grouped in Table II according to the capacity of the channels. It is interesting to note in this table the fairly constant decrease in the average loss in per cent per mile as the capacity increases.

TABLE II.—*Summary of seepage measurements expressed in terms of per cent of total flow lost per mile of channel for various sized canals.*

Capacity of canal (second-feet).	Number of tests.	Average loss per mile.	Capacity of canal (second-feet).	Number of tests.	Average loss per mile.
		Per cent.			*Per cent.*
Less than 1	16	25.7	50 to 75	31	4.3
1 to 5	37	20.2	75 to 100	26	2.7
5 to 10	30	11.7	100 to 200	45	1.8
10 to 25	49	12.1	200 to 800	27	1.2
25 to 50	48	5.5	800 and over	14	1.0

THE CARRYING CAPACITIES OF CONCRETE-LINED CANALS.

The laws governing the flow of water in concrete-lined channels do not differ from those for any other waterway. The force of gravity which produces motion in the water of a canal on a given grade is usually quite evenly counterbalanced by the various conditions which retard flow. These retarding influences are: (1) The frictional resistance of the wetted perimeter of the channel; (2) the influence of air in motion; (3) the existence of sharp curves, projecting objects, and irregularities of cross section, alignment, and grade; (4) the presence of sand, gravel, stones, or other shifting material; and (5) the presence of aquatic vegetation in the water or any rough coating on the perimeter of the canal.

The study of hydraulics has not yet reached that stage which will justify the assignment of definite values to the various influences which retard flow and thereby lower the efficiency of irrigation canals. One can do little more than consider all such factors collectively and designate them by the common term "frictional resistance." This has been done in the empirical formula known as Kutter's, where the letter n, called the coefficient of friction, represents not only the degree of roughness of the channel but all the other retarding influences to which reference has been made.

All the data pertaining to the carrying capacities of concrete-lined canals procurable at this writing (March, 1914) have been assembled and summarized in Table III. These results have been derived from a number of sources and represent rather wide differences in channel conditions. They likewise represent the work of a number of engineers who have employed somewhat different methods in making the necessary measurements. They are therefore not strictly comparable, but may be used as a basis for general deductions.

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
Idaho.		*Feet.*	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Ridenbaugh, Boise Valley	Trapezoidal slopes 1½ to 1.	10	4.24	294	2.75	0.000237	0.114	484
		10	4.28	294	2.76	.000262	.229	875
		10	4.35	294	2.81	.000170	.058	340
		10	4.30	294	2.81	.000237	.401	1,699
		10	4.58	318	2.96	.000245	.408	1,665
		10	4.15	257	2.69	.000242	.358	1,478
		10	......	50	1.30	....	......	1,000–2,400
		10	......	103	2.13	....	......	1,000–2,400
		10	......	230	2.73	....	......	1,000–2,400
		10	......	382	3.29	....	......	1,000–2,400
		10	......	50	1.30	....	......	1,000–2,400
		10	......	103	2.06	....	......	1,000–2,400
		10	......	230	2.72	....	......	1,000–2,400
		10	......	382	3.24	....	......	1,000–2,400
		10	......	376	3.11	....	......	1,000–2,400
		10	......	318	2.90	....	......	1,000–2,400
		10	......	59	1.37	....	......	1,000–2,400
King Hill, Snake River	Trapezoidal slopes 2 to 1.	16	2.17	92.5	1.71	.000187	0.121	650
		10	1.62	54.5	1.25	.000452	.167	369
		10	1.62	54.8	1.25	.000448	.248	556
		10	1.62	54.6	1.25	.000450	.415	925
Boise Main Canal, section No. 2, Boise Valley.	Trapezoidal slopes 1½ to 1.	40	......	316	2.14	.000300	.300	1,000
		40	......	1,027	3.88	.000388	.388	1,000
		40	......	476	2.64	.000362	.362	1,000
		40	......	245	1.95	.000288	.288	1,000
		40	......	119	1.44	.000288	.288	1,000
		40	......	1,209	4.22	.000312	.312	1,000
Boise Main Canal, section No. 3, Boise Valley.	....do......	40	......	1,011	4.33	.000263	.630	2,400
		40	......	470	2.45	.000334	.800	2,400
		40	......	470	2.65	.000246	.590	2,400
		40	......	238	1.87	.000300	.720	2,400
		40	......	238	2.09	.000204	.490	2,400
Boise Main Canal, section No. 4, Boise Valley.	....do......	40	......	1,027	3.64	.000316	.757	2,400
		40	......	456	2.89	.000147	.353	2,400
New York Canal, Payette-Boise.	Trapezoidal.	39.6	5.6	1,824	5.23	.0001611	0.097	602
Ridenbaugh, Boise	.....do......	10	2.7	221	2.54	.000251	0.226	901
Do	.....do......	10	3.2	316.7	2.91	.000283	......	1,020.6
Twin Falls North Side, near Milner.	Nearly rectangular.	40	......	2,637	5.434	.000639	2.132	1,900
Oregon.								
Umatilla, U. S. Reclamation Service project.	Trapezoidal slopes 1¼ to 1.	1.5	......	5.7	.58	.00070	.652	932
Do	Semicircular	[1] 4.9	......	205	2.13	.00140	.9	640
		[1] 4.9	......	205	2.17	.00167	.2	120
		[1] 4.9	......	205	2.15	.00273	.6	220
		[1] 4.9	......	205	2.12	.00177	1.9	1,075

[1] Radius.

elements, value of "C" in Chezy's formula and "n" in Kutter's formula.

Velocity feet per second.	C in Chezy formula.	n in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
4.23	165.5	0.0106	Current meter.	Level and hook gage.	Lining consists of 3½ inches concrete base with ½ inch mortar coat. Depth 6.5 inches with 1 foot concrete berm on top. Maximum depth of water 6 feet. Surface equivalent to sidewalk finish.	Tangent; practically no gravel.	Unpublished records of Office Irrigation Investigations. Measurements by Don H. Bark.
4.18	155.2	.0114				Reverse curve; a few cobblestones.	
4.08	187.0	.0095				Tangent; a few cobblestones.	
4.15	161.5	.0110				Total of above 3...	
4.13	153.5	.0116				Same 2 months later, more gravel on bottom.	
3.82	149.6	.0118				Same 2 months later still.	
2.45	119	.0132	..do.....	Gages.....	Same as above. Surface very smooth.	Numerous curves.	Records of U. S. Reclamation Service. Measurements by W. G. Steward under the direction of F. W. Hanna.
2.32	130	.0130					
3.35	145	.0122					
3.99	147	.0124					
2.43	123	.0127					
2.45	129	.0131					
3.37	158	.0112					
4.08	141	.0118					
4.32	142	.0126					
4.15	138	.0129					
2.60	130	.0122					
2.06	115.2	.0140	..do.....	Level and hook gage	Lining 4 inches thick, hand tamped; no surface coat; rough finish; no moss.	Partly tangent....	Unpublished records of Office of Irrigation Investigations. Measurements by Don H. Bark.
2.54	107.3	.0144				Nearly all curves..	
2.55	108.1	.0143				One curve........	
2.55	107.5	.0143				Combination of above two.	
3.08	121	.0140	..do.....	Level, and with gages chipped into concrete every 200 feet.	Rough troweled surface. First measurements had considerable rock and stone in bottom, others had only a small quantity.	All tangent, gaged 500 feet below inlet and 300 feet above outlet.	Records of U. S. Reclamation Service. Measurements by W. G. Steward under direction of F. W. Hanna.
4.68	121	.0154					
3.57	115	.0152					
2.64	111	.0149					
1.84	91	.0170					
4.91	135	.0139					
3.90	116	.0164	...do.....	...do.......	Much gravel in bottom.	Tangent...........	Same as above.
3.81	133	.0130	..do.....	...do.......	Very little gravel in bottom. Concrete rather rough and some of it disintegrated due to freezing during construction.	....do.............	Do.
3.48	136	.0129					
2.67	113	.0147					
2.35	114	.0148					
5.00	148	.0124	..do.....	...do.......	Similar to set above. Concrete troweled to smoother surface.	Number of sharp curves.	Do.
2.98	145	.0123					
5.48	188.7	.0101	Vertical curves.	Level and hook gage.	Medium rough concrete, plastered joints.	Tangent............	F. C. Scobey, Irrigation Investigations.
3.65	144.8	.0121	...do.....	...do.......	Very smooth cement wash on concrete.	.....do............	Do.
4.14	......	.0124	...do.....	...do.......	.....do...............	One slight curve approximately same as above.	B. P. Fleming, Irrigation Investigations.
8.21	139	.0138	...do....	...do.......	Rough rock cut rather lightly concreted, leaving an irregular undulating surface.	Tangent............	F. C. Scobey, Irrigation Investigations.
2.06	102	.013	Current meter.	Level and gages.	Surface smooth and regular.	Slight curve.......	Records of U. S. Reclamation Service.
7.10	129	.0132	..do.....	...do.......	Concrete built with forms not troweled. Grain of lumber shows.	Tangent...........	Do.
6.86	114	.0149				All on curve with 100-foot radius.	
6.94	90	.0189				All on curve with 50-foot radius.	
7.15	119	.0142				Slight curve.......	

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
Oregon—Continued.		*Feet.*	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Central Oregon Irrigation Co.'s north canal, Bend.	Trapezoidal.	12	......	25.7	0.883	.00095	0.221	240
		12	......	74.86	1.627	.000629	0.151	240
		12	......	98.3	1.952	.000525	0.124	240
Utah.								
Davis & Weber, near Ogden.....	Trapezoidal slopes 1 to 1.	22	2.70	208	2.24	.000409	......	....
		22	2.65	202	2.21	.000409	......	....
		22	2.70	201	2.27	.000409	......	....
		22	2.73	192	2.26	.000409	......	....
		22	2.34	162	1.98	.000417	......	....
		22	2.25	170	1.92	.00050	......	....
		22	1.60	122	1.43	.00050	......	....
		22	1.81	150	1.57	.00050	......	....
		22	1.49	102	1.31	.00050	......	....
		19	1.75	133	1.50	.000626	......	....
		19	1.13	68	1.01	.000626	......	....
		19	1.50	113	1.31	.000626	......	....
Davis & Weber Flume Canal, near Ogden.	Trapezoidal.	18.5	......	120.9	1.50	.000619	......	468.5
Do........................	....do......	19	2.34	212	2.07	.000629	0.629	1,000
South Cottonwood, Ward Canal, Murray.	Trapezoidal but nearly rectangular.	25±	......	2.86	.520	.000694	0.232	350
Washington.								
Sulphur Creek Wasteway, Reach No. 4, Sunnyside project, U. S. Reclamation Service.	Semicircular	[1] 4	......	52.5	0.69	.0205	18.46	900
		[1] 4	......	247	1.37	.0207	18.61	900
		[1] 4	......	242	1.36	.0206	18.57	900
Sulphur Creek Wasteway, Reach No. 6, Sunnyside project, U. S. Reclamation Service.	......do......	[1] 4	......	52.5	.67	.0144	18.80	1,300
		[1] 4	......	45.0	.62	.0145	18.85	1,300
		[1] 4	......	247	1.33	.0144	18.71	1,300
		[1] 4	......	242	1.30	.0144	18.79	1,300
Montana.								
Hamilton Flour Mill, Hamilton..	Rectangular with fillet.	7	4.11	107.6	1.94	.00062	......	3,000
California.								
Lateral 12, Orland project, near Orland.	Trapezoidal with dished bottom.	4±	......	5.71	.543	.000990	0.204	206
Sanderfer Ditch Co.'s main canal, Whittier.	Trapezoidal.	2.5±	......	18.71	.842	.002376	1.812	743.3

[1] Radius.

elements, value of "C" in Chezy's formula and "n" in Kutter's formula—Continued.

Velocity feet per second.	C in Chezy formula.	n in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
2.10 2.85 2.94	72.5 90.8 92.5	.0192 .0176 .0177	Vertical curve.	Level and hook gage.	Extremely rough concrete.	Tangent. Sharp curves adjacent each end and a very rough rock cut beginning about 200 feet below this section.	F. C. Scobey, Irrigation Investigations.
3.12	103	.0166	Current meter.	Level; grade of bottom for long lengths taken as slope of water surface.	Expansion joints 12 feet apart usually, some 8, 10, and 16 feet, made by inserting temporary wooden strips. Through neglect of management the wooden strips were not removed and asphalt inserted, but projected in some cases from 1½ to 2 inches above surface and impeded flow. These were more frequent in the upper portion. There was also some gravel on the bottom in the upper portion. Concrete placed without forms, finish of average smoothness.	Mean of 3 measurements.[1]	Unpublished records of Office Irrigation Investigations. Measurements by E. R. Barrett under direction of W. W. McLaughlin.
3.09	103	.0165				Mean of 5 measurements.[2]	
2.97	97	.0176				Mean of 6 measurements.[2]	
2.84	94	.0182				Mean of 3 measurements.[2]	
2.76	97	.0171				Mean of 3 measurements.[2]	
3.06	99	.0168				Mean of 5 measurements.[2]	
2.86	105	.0151				Mean of 4 measurements; depth 0.83 to 2.18.[2]	
3.16	112	.0142				Mean of 5 measurements; depth 0.8 to 2.27.[2]	
2.55	99	.0156				Mean of 5 measurements; depth 0.67 to 2.33.[2]	
3.89	110	.0144				Mean of 8 measurements; depth 0.85 to 2.45[2]	
2.62	104	.0141				Mean of 7 measurements; depth 0.6 to 1.87.[2]	
3.25	113	.0138				Mean of 8 measurements; depth 0.6 to 2.29.[2]	
3.34	......	.0146	Vertical curves.	Level and hook gage.	Medium smooth concrete.	Wooden strips at joints projecting 1¼ to 1½ inches.	B. P. Fleming, Irrigation Investigations.
3.94	109.7	.0154	...do.....	...do.......	.....do...............	Wooden strips at joints projecting 1¼ to 1½ inches.	F. C. Scobey, Irrigation Investigations.
1.38	72.6	.0171	Current meter, integ.	...do.......	Rough concrete, influence disappeared through deposit of slime and moss.	Tangent with slight curve.	Do.
12.4 19.3 19.1	104.3 114.4 114.1	.0136 .0140 .0140	Current meter in main canal.	Level and hook gages in wells.	Concrete deposited against wood forms; no retouching of surface.	On 2° curve.......	Records of U. S. Reclamation Service.
13.1 12.5 20.4 20.6	133.1 131.7 147.8 150.5	.0109 .0109 .0110 .0108	..do.....	...do.......	.....do...............	Tangent............	
3.86	111.4	.0149	Vertical curves.	Level and hook gage.	Fairly smooth concrete.	Slight amount of moss, new flume.	S. T. Harding, Irrigation Investigations.
1.86	80.2	.0160	...do.....	...do.......	Fairly smooth cement finish.	Some gravel on bottom.	F. C. Scobey, Irrigation Investigations.
3.75	92.0	.0155	...do.....	...do.......	Smooth cement wash concrete.	Tangent roughened by a dark deposit.	Do.

[2] Alignment contains many curves.

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
California—Continued.		*Feet.*	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Santa Ana main canal, near Anaheim.	Trapezoidal.	10	......	27.16	1.215	.000321	0.328	1,082.8
Modesto Irrigation District main canal, near La Grange.	.....do.......	20	......	114.8	1.381	.001157	0.874	755.6
Arroyo Ditch & Water Co.'s main canal, near Whittier.	.....do.......	3	......	18.54	0.951	.001449	1.449	1,000
Los Nietos Water Co.'s main canal, near Whittier.	....do.......	2	......	19.36	.983	.001444	0.971	600.5

elements, value of "C" in Chezy's formula and "n" in Kutter's formula—Continued.

Velocity feet per second.	C in Chezy formula.	*n* in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
1.67	87.1	.0176	Vertical curves.	Level and hook gage.	Medium smooth concrete; 0.1 to 0.2 foot of sand in bottom; rough with hard deposit about ½ inch thick.	....	F. C. Scobey, Irrigation Investigations.
3.59	89.7	.0174	...do.....	...do.......	Fairly smooth concrete with no vegetable growth. Tangent.	A few loose rocks in canal and right angle turn below section accounts for high "n."	Do.
2.83	76.2	.0188	...do.....	...do.......	Rough finish with combined vegetable and mineral deposit.	Tangent...........	Do.
2.89	76.5	.0197	...do.....	...do.......	Fairly smooth cement finish roughened by a dark deposit.	Shifting sand on bottom.	Do.

Perhaps the most important conclusion to be drawn from the 76 measurements of the 18 canals summarized in the table is that the so-called coefficient of friction n is on an average larger than has usually been assumed by engineers. The results show that only in rare cases, where conditions are more or less ideal, is one justified in assuming a value as low as 0.012 for n. The Ridenbaugh Canal of the Nampa and Meridian irrigation district of Idaho, shown in Plate XVII, figure 2 (p. 80), belongs to this class. The flow in this concrete-lined canal has been measured by at least five engineers and their average result as regards the value of n is a trifle below 0.012. In the results given in the table, one also finds a value of n as high as 0.0197 and five others greater than 0.018. Again, in the concrete-lined canals of southern California a coating consisting of a vegetable and mineral accumulation was found adhering to the perimeters. The effect of this coating on the flow of water is seen in the high coefficient of friction for these channels as given in Table III. This coating may be observed in Plate I, figure 1, which shows a portion of the Santa Ana Canal near Orange, Cal.

The following approximated values for n may serve as a guide to those who are required to estimate, prior to construction and operation, the discharge of lined canals.

I. $n=0.012$ for concrete-lined canals having a smooth sidewalk finish, clean bottom, no moss, uniform cross section, well-formed joints, long tangents, flat spiral curves, no perceptible undulations on the surface of the water, and in general the best construction and the best conditions obtainable in practice.

II. $n=0.013$ for concrete-lined canals having conditions slightly better than those of Type III and not so good as those of Type I.

III. $n=0.014$ for concrete-lined canals having an unplastered or rough troweled surface, clean bottom, uniform cross section, well-formed joints, medium curvature, no spirals, slight surface undulations, no aquatic vegetation, and in general good construction and favorable conditions.

IV. $n=0.015$ for concrete-lined canals having conditions similar to those of Type III, but with greater curvature and some débris or other retarding influences.

V. $n=0.016$ for concrete-lined canals of average workmanship and medium conditions, having a rough surface, imperfect joints, and sharp curves; also for canals of smooth lining and good workmanship, but having one or more unfavorable conditions, such as sand and gravel in the bottom or projecting joints which decrease the velocity of water.

VI. $n=0.017$ for concrete-lined canals roughly coated, but otherwise in medium condition.

VII. $n=0.018$ [1] for concrete-lined canals coated as in Type VI and having the bottom more or less covered with sand and gravel, or else a clean bottom but poor alignment, irregular cross section, broken gradient, or the like.

OTHER KINDS OF LINING.

Experiments were made by this office in 1906 in cooperation with the University of California [2] to determine the cost and relative merits of different kinds of canal lining. A series of short experimental ditches were excavated in a field in Stanislaus County, Cal., about 4 miles east of the town of Modesto. The channels used were 50 feet long, had a bottom width of 2 feet, a depth of 2½ feet, and a slope of 1½ to 1 on both sides and ends.

The experiments were continued under the direction of the writer the year following on the same site, and a similar set of experiments were also conducted on the university farm at Davis, Cal. The results obtained in 1907 at both sites did not agree with those published in the progress report and in consequence the final report was not published. The belief is quite general, however, that the report of the results obtained in 1906 [2] tended to give erroneous impressions as to the relative merits of certain kinds of linings. This is especially true of oil lining. The Lemoore Canal & Irrigation Co. of Kings County, Cal., was cited as an example where heavy crude petroleum containing a high percentage of asphaltum had been successfully used in lining 1½ miles of their main canal. It would appear that this experiment did not prove altogether satisfactory since the company which tried it has discontinued the use of this kind of lining. Other investigations have shown that oil lining is not effective for a long period of time. Even in California where a heavy oil containing a large percentage of asphaltum can be purchased for about 2 cents per gallon, practically no canals have been lined, to the writer's knowledge, with this material in the past five years.

When lumber was cheap and cement expensive it was common practice in the West to line the weak and leaky portions of canals with lumber in the form of flumes. The short life of wood, particularly where it is in contact with moistened earth and exposed to the air, the high cost of maintenance, the high cost of lumber, and the somewhat lower cost of cement have all tended to lessen the use of wooden lining.

Reference has already been made to the advantages of a natural lining of silt derived from the earthy impurities borne by the water in the canals. A clay puddle may likewise serve as an effective bar-

[1] The value of n for some concrete-lined canals exceeds 0.018. In such cases, however, the increased carrying capacity due to lining is counterbalanced or nearly so by deposits of débris in the bottom, aquatic vegetation, or other causes.

[2] California Sta. Bul. 188 (1907).

rier against the escape of water. If the bottom of a new canal in porous material is covered with a layer of clay, moistened, and then used as a feeding ground for domestic animals it may be rendered quite impervious. Some of the thoroughly worked clay can afterwards be removed from the bottom and placed on the slopes. When domestic animals are not available to mix the clay, it should be done by harrowing and packing. A layer of coarse gravel spread over the clay lining and tamped into it may prevent the erosion of the clay and render it more effective.

THE ECONOMY OF CONCRETE LINING.

In determining the economy of concrete lining for a given canal, one has to consider and compare the cost and benefits of such work. Itemized statements of the cost of concrete lining for various canals are given in another part of this report. The principal benefits to be derived from lining are briefly discussed under the following heads:

(1) *Seepage water and its value.*—The possible saving in seepage losses by lining can be readily determined for canals already in use, and the portions in which this is important can be located by measurements of the discharge. In some cases the loss in short distances may be sufficient to make the lining of these desirable, although it would not be practicable to line the canal as a whole.

In the case of a new canal, a reasonably close estimate of the seepage losses which are likely to occur may be made from the data given in Table I.

In nearly every irrigated district of the West water which can be saved through the prevention of seepage has a value. As the demand for water increases the value of any saving will also increase until methods of canal lining at present too expensive to be considered may become practicable. The value of the water which may be saved varies widely in the different portions of the country. On the larger systems now being constructed, water rights are being sold for from \$25 to \$50 per acre, and in some cases for even higher prices.

Based on the final estimated cost and acreage included, the average estimated cost per acre July 1, 1910, was \$48.14 for the United States Reclamation Service projects and \$21.75 for the Carey Act projects. The duty of water delivered under these rights is also variable and will probably average 1 second-foot to 100 acres. Inasmuch as any saving in canal seepage can be delivered to the user with small additional loss, each 0.01 second-foot saved should make it possible to serve another acre. The additional expense required for such irrigation would be for the lateral system only, as the storage and diversion works would not be affected. On this basis each second-foot of water which can be saved should have a value of from \$2,500 to \$5,000. Allowing \$750 for the additional cost of the distributing system leaves

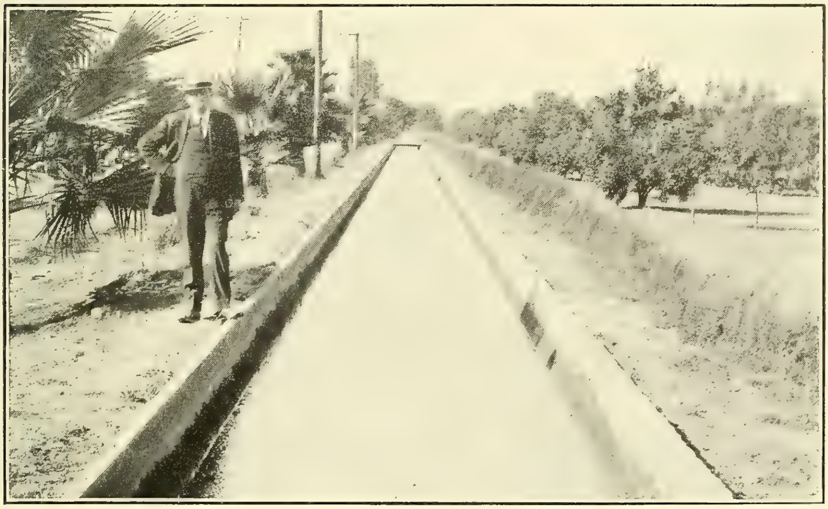


FIG. 1.—SANTA ANA CANAL NEAR ORANGE, CAL.

(Showing moss and mineral accumulation on wetted surface.)

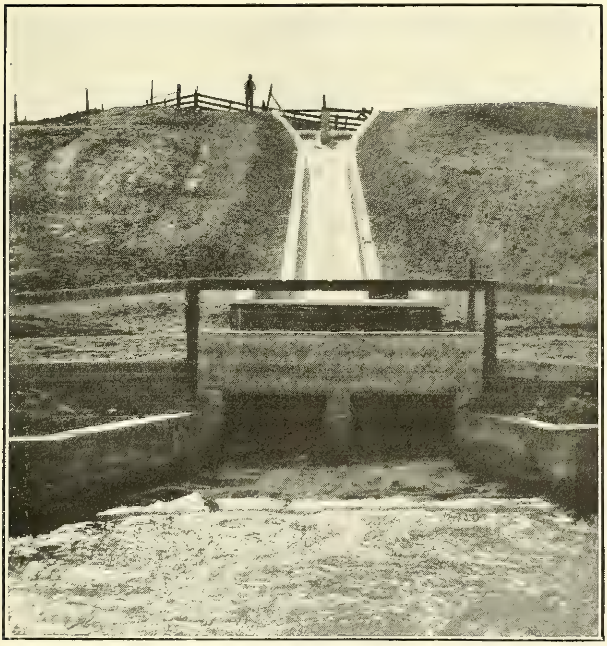


FIG. 2.—BY-PASS CHUTE, ORLAND PROJECT, U. S. RECLAMATION SERVICE, ORLAND, CAL.

(From a photograph furnished by A. N. Burch, project manager.)

$3,000 as a general average for the value of each second-foot saved by lining.

(2) *Increase in carrying capacity.*—The volume carried by a canal in earth is as a rule much less than that carried by a concrete-lined canal of the same dimensions and grade. This is due to the smoother perimeter of the latter, and its greater uniformity in cross section, alignment, and grade. The discharge of a typical canal in earth having a mean velocity of 2.5 feet per second and a coefficient of friction (n in Kutter's formula) of 0.0225, may be increased from 25 to 80 per cent by lining with concrete. A gain of 25 per cent in the volume carried is readily obtained as the result of lining, but to secure a gain of 80 per cent involves the construction of first-class lining and conditions favorable to the maximum discharge of water in such channels.

(3) *Reduction of charge for operation and maintenance.*—On many systems, particularly where the canal follows a side hill, much difficulty is encountered from breaks on the lower bank when the canal is crowded to its full capacity or when an opening may be made by a gopher or other burrowing animal. A concrete lining should prevent such breaks except in cases where the water overtops the bank due to stoppage or other causes. Faulty location of the canal and weak places developing later can very often be largely corrected by a good concrete lining. Where the original grade is such that scour occurs, or where excessive curvature causes cutting of the sides, a similar remedy may be used. Maintenance charges also will be materially reduced by the lessening of weed growth and the prevention of the shifting of the channel through scouring. In some systems the fall of the country is too great to be taken up by the grade of the canal and many drops are required which may form a considerable proportion of the cost and necessitate high maintenance expenses. The use of a concrete lining frequently permits a sufficiently high grade to be used so that no drops are needed, the saving in these structures paying part of the cost of the lining.

(4) *Insurance against damage to crops.*—As the losses from the lack of water at critical times during the irrigation season are often much greater than the actual cost of repairs, a portion of the cost of any canal lining may be considered as an insurance against such accidents. An instance of this occurred on the Turlock Canal, of California, in 1910, when a break thought to have been due to a gopher hole caused 1,000 feet of the main canal on a steep side hill to be washed out. The canal was out of service for six weeks during the period when water was most needed for crops. The actual cost of repairs was $20,000, but the estimated damage to crops was $1,000,000.

SUITABLE GRADES FOR LINED CANALS.

In deciding upon suitable grades, cross sections, and alignment for lined canals, one has to take into account the two types of canals which are lined. One of these is represented by the canal in operation designed for earth, the other by the new canal designed for concrete lining.

The grade which is suitable for a canal in earth is not the most economical grade for the same canal when lined with concrete. It is not, however, feasible to make any material change in the grade of an old canal preparatory to lining it. The irregularities can and should be removed so as to secure a uniform gradient, but more than this can not be done without changing the location.

The discussion of suitable grades must therefore be confined in this report to new canals intended to be lined before carrying any large percentage of their maximum capacity. Disregarding all other features and considering only the most economical method of conveying water, the steep grade with its correspondingly high mean velocity is best. The fact is now fairly well established that water can pass over a concrete surface at a high velocity without injurious effects. It is only when fast-flowing water strikes against concrete or is obstructed by it that damage is likely to result. Mr. A. P. Davis, chief engineer of the Reclamation Service, cites a case[1] in which a concrete chute on the south canal of the Uncompahgre project, discharging 300 cubic feet per second at a velocity of over 20 feet per second for one year, not only showed no perceptible wear, but it had acquired a growth of slimy moss over the concrete surface subject to this velocity.

In the summer of 1913 Justin T. Kingdon, of this office, made an examination of a concrete chute (Pl. I, fig. 2) on the main canal of the Orland project, Orland, Cal. The canal maintains a fairly constant flow throughout the season. It was measured shortly after the observation and found to be discharging 84 second-feet of water which at the bottom of the chute had a velocity of 17 feet per second, and like the south canal of the Uncompahgre project, this concrete showed no wear on its wetted area, and the growth of slimy moss which it had acquired was especially noticeable over that portion of the surface subject to the highest velocity.

It would therefore appear that the permissible velocity in lined canals depends largely on considerations other than damage to the lining. The mention of three of these causes may serve to make this statement clear. Assuming that a concrete-lined canal will successfully withstand velocities up to 20 feet per second, the fall necessary to produce such velocities must be considered, since

[1] Eng. News, 67 (1912), No. 1, p. 20.

the sacrifice of so much head might entail greater cost than the building of a larger canal on a lighter grade.

Again, the extra cost and inconvenience in making suitable turnouts to divert water from such a canal would serve to lessen the advantages gained by having a high velocity.

Lastly, pulsations are a common feature in all channels in which the water flows at a high velocity. The water surface consists of irregular waves which travel at various distances apart and an extra height of lining is required to prevent the waves from overtopping it.

It is believed that a mean velocity of between 8 and 10 feet per second is about as high as should be adopted in lined canals under ordinary conditions.

ALIGNMENT OF LINED CANALS.

In locating a new canal for concrete lining, sharp curves should be avoided if possible. The reduction of curvature in a location over a rough country with steep slopes may increase considerably the amount and the cost of excavation, but this additional expense may be more than compensated by the advantages gained in having flat curves.

In flowing around curves the surface of the water tends to rise on the outer side due to centrifugal force. The height to which it will rise in any given case will depend on the velocity of the water and the sharpness of the curve. In order to maintain a uniform height of lining above the water surface of the canal, the practice has been to raise the outer lining. In the case of the Tieton main canal of the United States Reclamation Service, Yakima project, Washington, on the sharpest curves, having a radius of 57.6 feet and a velocity of 9 feet per second, the superelevation amounted to about 1 per cent of the width.

The presence of a large number of sharp curves likewise increases the cost of both the earth trimming and the laying of the concrete.

In railroad location it is customary to limit the curvature within a certain fixed maximum regardless of expense, but in the construction of irrigation canals, on account of the wide range permissible, it has not been customary to fix any such limit. The expense of excavation required to lessen curvature should be balanced against the disadvantages and extra cost of lining sharp curves.

THE EFFECT OF ALKALI ON CONCRETE LINING

Throughout the West are to be found here and there instances of concrete construction having been disintegrated through the action of alkali salts. While some uncertainties remain regarding the exact nature of such action, there seems to be no question but that the principal reason for it arises from the reaction between the various alkali salts and the calcium hydroxid of the cement. The new compounds formed have a greater volume than the replaced hydroxid and their formation weakens or destroys the concrete by forcing apart the particles of cement. In order for this action to occur it is necessary for the water containing alkali to percolate into or through the concrete. Under field conditions [1] "these reactions referred to are much

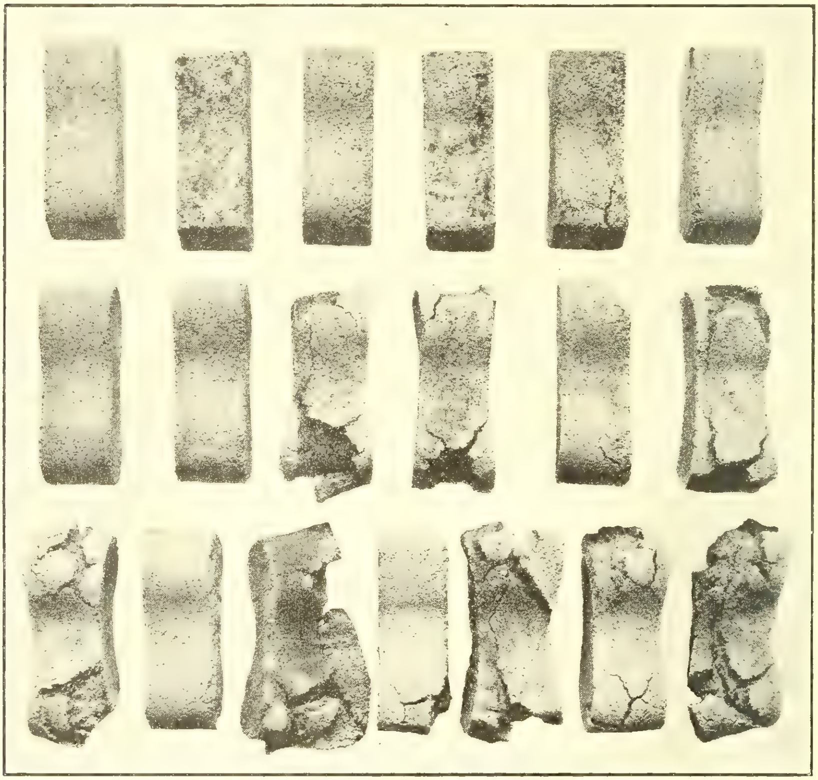


FIG. 1.—Briquets showing repellent action of oil-cement concrete on alkali water. (From tests by the Office of Public Roads, United States Department of Agriculture.) Top row contained 10 per cent of semiasphaltic oil; middle row contained 5 per cent of semiasphaltic oil; bottom row contained no oil. Briquets were immersed one year in a 10 per cent solution of sodium sulphate.

retarded if not entirely suspended in most cases, due probably to the carbonization of the lime of the cement near the surface or the formation of an impervious skin or protective coating by saline deposits."

It is also doubtless true that [2] "wetting and drying or freezing and thawing will hasten the destruction of the cement by extending the cracks already started."

[1] U. S. Dept. Com., Bur. Standards Technol. Paper 12 (1912).

[2] Montana Sta. Bul. 81 (1910).

In experiments with oil-mixed Portland cement concrete,[1] the concrete was damp-proofed by the incorporation of semiasphaltic oil. In hand mixing, the sand, cement, and water were first mixed to a mushy consistency, the oil added and mixed until no trace of it was visible on the mortar surface, and then the broken stone or gravel was mixed in. In machine mixing the sand, cement, and water were first mixed to a mortar followed by alternate batches of stone and oil which were added and mixed. The proportion of oil used was based on a comparison of its weight to the weight of the cement used in the concrete. The results of tests show that oil-mixed mortar, containing 5 to 10 per cent of oil, is dampproof as well as waterproof, and indicate that its use may prove desirable in the construction of irrigation canal linings exposed to the action of alkali (fig. 1).

Good practice in concrete lining construction where alkali must be reckoned with necessitates the following precautions:

(1) Do not use sand, gravel, or water containing alkali.

(2) Keep soil waters charged with alkali from coming into contact with the concrete by the use of suitable drainage.

(3) Give careful attention to the proper proportioning of materials and use more cement than is needed to fill the voids.

(4) Protect the surface by a thin plaster coat of dense mortar of granular sand.

(5) Both the concrete and the mortar used for the lining may be dampproofed by the addition of 5 to 10 per cent of semiasphaltic oil when mixing the materials.

THE EXPANSION AND CONTRACTION OF CONCRETE.

FIELD TESTS AT LOGAN, UTAH.

During the summer of 1913 field experiments were conducted by Prof. B. P. Fleming, of the State University of Iowa, working under the direction of this office, at Logan, Utah, for the purpose of determining the coefficient of expansion of concrete slabs. An effort was made to secure conditions as nearly as possible like those found for canal linings. It will be noted, however, that the slabs were not tested to find the effect produced by being wet on one side.

The variations in length were measured with two micrometer microscopes focused upon lines in the highly polished tops of two steel pins projecting above the surface of the slab, one at each end. This device permitted making direct readings from the micrometer scale, giving measurements to 0.0008 of a millimeter. The thermometers used were graduated to 0.10° C. and could be estimated easily to 0.025°. All measurements of the slab length were direct, and no part of the apparatus was in contact with the slab. The idea of maintaining the latter condition was to prevent in every possible way influences which might affect the expansion of the slab.

[1] U. S. Dept. Agr., Office Pub. Roads Bul. 46 (1912).

Except for a roller placed under one end, each slab was lying on ground composed mostly of loose gravel.

The slabs were 12 inches wide, 6 inches deep, and 11 feet long. The steel pins inserted vertically in the top were spaced 10 feet apart, thus leaving 6 inches length of slab beyond the pin at each end. A wet hand-mixed concrete mixture was used for each slab, numbered 1 and 2, and volumetrically proportioned 1:3:5 and 1:2:4, respectively. Each slab was of rectangular cross section throughout.

The general average coefficient of expansion measured was 0.0000043 for slab 1 and 0.0000042 for slab 2.

LABORATORY TESTS AT THE STATE UNIVERSITY OF IOWA.

In the fall and winter of 1913–14 the experimental work initiated at Logan, Utah, was continued in the laboratory of the State University of Iowa under the same supervision as before.

The sand and gravel used were taken from the bed of Iowa River. This raw material was screened through a 1-inch mesh screen and again through a $\frac{1}{4}$-inch mesh screen. The material failing to pass the latter screen was considered gravel. The sand was unscreened, but it was fine and clean.

Three horizontal slabs were cast with the same dimensions as those made at Logan. The apparatus and equipment were practically the same, except that the laboratory permitted a somewhat careful control of influencing conditions not possible in the open-air work. In addition, a specially devised apparatus permitted the making of observations for change of length within 30 minutes after water had been added to the dry materials used in making the concrete. Brass pins with their upper ends highly polished were used instead of steel pins. The methods employed for temperature determination and control were quite satisfactory and it is believed gave results fully as accurate as the investigations warranted.

Two slabs of seasoned concrete were used for determining the coefficient of expansion. A third one was used to determine the influence on change of length due to setting. Each slab was made of hand-mixed concrete, using the materials composing the concrete in the following proportions:

Proportions of materials used in making concrete slabs.

Mixture.	Number of slab.		
	1	2	3
By volume:			
Cement	1	1	1
Sand	3	2	3
Gravel	5	4	5
By weight:			
Water	100	72	75
Cement	118	99	79
Sand	319	203	244
Gravel	552	441	431

The general average coefficient of expansion measured was 0.00000627 for slab 1 and 0.00000632 for slab 2.

Slab 3 was kept at a temperature of about 80° F., though at times it fell to 70° and even 65° during Saturdays and Sundays. Daily observations were made early in the work, but later on observations were made only once a week. It is interesting to note (fig. 2) the immediate and rapid expansion following pouring, lasting about one week. This caused a change of length of about 0.00012 foot per foot. This action was doubtless due to the physical rearrangement of the particles of concrete in the process of crystallization. So far as its effect upon concrete lining for canals is concerned, if joints were not provided, it would cause severe compression of the slab as a whole for about a week or 10 days, which might cause a slight buckling and crushing. Where joints are used and filled with asphaltum or similar material the tendency would be to force some of it out of place, and for this reason the filling material should not be placed until about two weeks after the lining has been laid. It will be noted, however, that the expansion is only 0.012 foot in 100 feet, which accounts for its effect being of no marked importance in practice.

It will also be noted (fig. 2) that following the expansion period in slab 3 there is a period of contraction lasting about 75 days and during which there is a total contraction at the rate of about 0.042 foot in 100 feet, thus leaving the slab 0.03 foot shorter for a 100-foot length than when laid. If this factor were considered for a concrete lining, assuming that its contact with the material through which the canal were constructed would not retard the expansion, having a coefficient of expansion of 0.0000045, it would allow a total rise of temperature of about 67° F. before two adjoining slabs would be in contact after the contraction due to setting had been completed. It is evident, therefore, that if a slab were laid in the winter at a temperature of 40° F., the joints opened by contraction would not be closed until the slab had reached a temperature of 106° F. in the summer. Concrete lining is usually placed in canals during the winter or at least when the weather temperatures are cold enough for the above conditions to obtain. If the water carried in the canal is at a temperature of between 40° and 60° F., it is evident that the effect of contraction in concrete lining laid at corresponding temperatures will be most noticeable at a time when water-tightness is most desired. For this reason it is essential that some provision be made to secure water-tight joints. It may also be quite necessary to use some elastic material like tar paper to allow for expansion in excess of that which can be taken up by the space formed due to contraction in setting, for in some sections of the West temperatures are likely to be met which will cause this extra expansion, and unless a compressible material is provided buckling or crushing is very likely to occur.

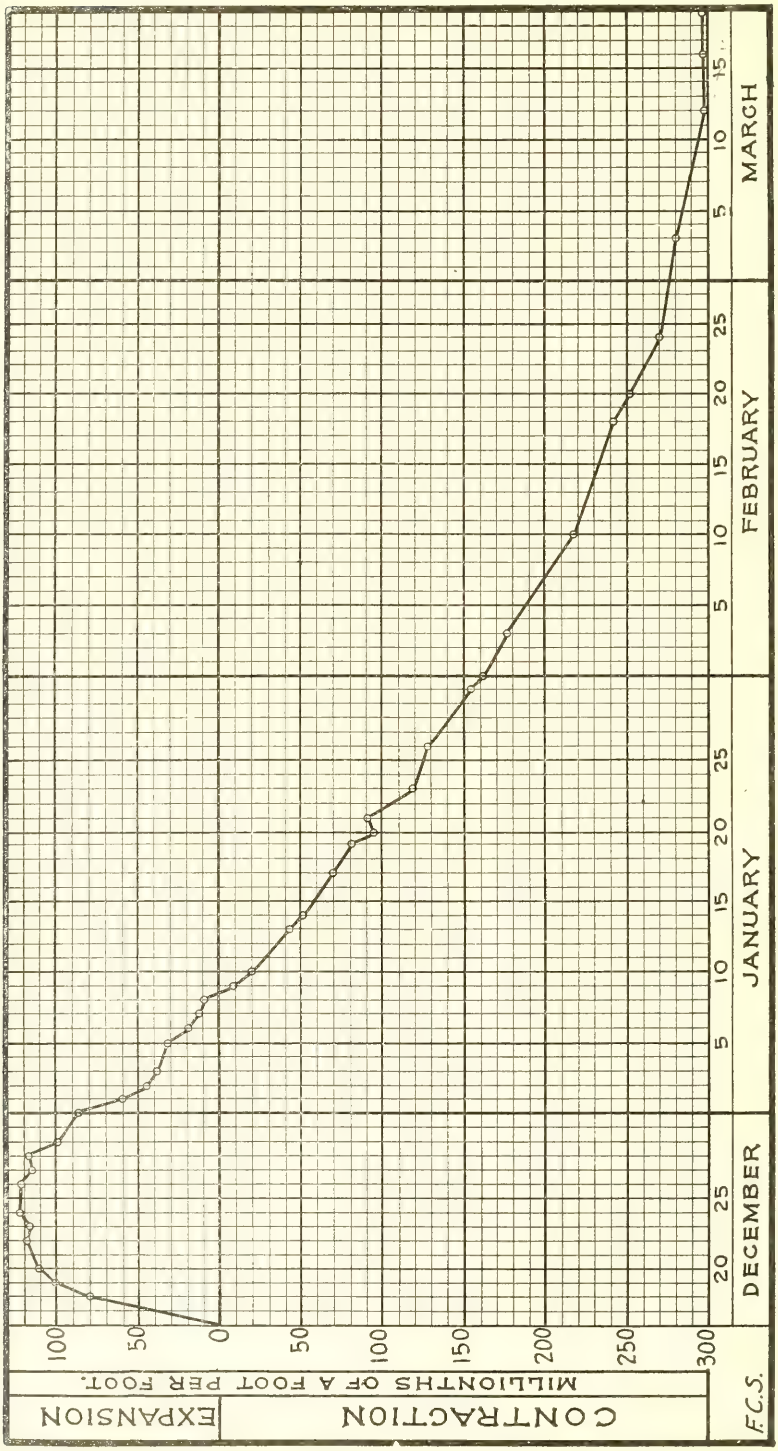


FIG. 2.—Curve showing expansion and contraction of concrete from actual measurements made on a 10-foot length of slab (measurements commencing within 30 minutes of time water was added to aggregate.)

In summing up the results of the experiments at Logan, Utah, and those at the State University of Iowa, it may be stated that for concrete slab construction such as canal lining, where only one side is exposed and with the other side in contact with earth, a coefficient of expansion of 0.0000045 should be used, but in the case of concrete construction where all sides are subject to equal temperatures and are not under the conditions of moisture and earth contact found in canal lining and similar construction, a coefficient of 0.0000063 can be used with safety.

JOINTS IN CONCRETE LINING.

Owing to the fact that concrete lining expands in warm weather and contracts in cold weather, joints would seem to be an essential feature of such construction. Where no provision is made for expansion and contraction by means of joints, the concrete lining is certain to be subjected to high internal stresses, which increase in intensity until the lining is ruptured. These ruptures occur at the weakest points, and following the directions of least resistance result in irregular fractures which are difficult to repair. They frequently are so small and so irregular that it is practically impossible to introduce any filler into the seams. Even when this is done the alternate opening and closing of the fracture, due to changes in temperature, lowers and in time destroys the effectiveness of such repairs.

On the other hand, joints in concrete lining constitute a weak feature. In strength, durability, and water-tightness the best formed joint is inferior to the continuous lining. For these reasons, to which may be added that of extra cost, the distance between joints should be as great as possible consistent with changes in volume due to temperature and the adoption of suitable forms and proper methods of construction.

When forms are used their length is usually limited to the size and weight which can be readily shifted by hand without the aid of special equipment. Even when the forms are of the simplest kind the methods of construction commonly employed place other limitations on the distance between joints. Again, in lining curves the frequency of the joints depends upon the degree of curvature, the sharper the curve the shorter the distance between joints. Notwithstanding these limitations, the tendency in the past has been to insert too many joints, particularly on straight portions of canals.

The subject of joints in concrete lining is also closely related to the manner in which the lining is laid, whether continuously or in alternate sections. Joints which are adapted to one of these methods may be a misfit when applied to the other. In using either method it is advisable to break joints between the floor and the sides, as indicated in figure 3, *a*.

KINDS OF JOINTS.

Various kinds of joints are used to prevent cracks in concrete linings:

(1) One of the most common is the plain abutting joint. This joint is simple, cheap, and easily made. Expansion, likewise, is provided for in the frequency of the joints. It has, however, several weak features which render its use questionable. One of these is the lack of any bond between the sections. Were it not for the connection with the bottom at the toe each side section might be

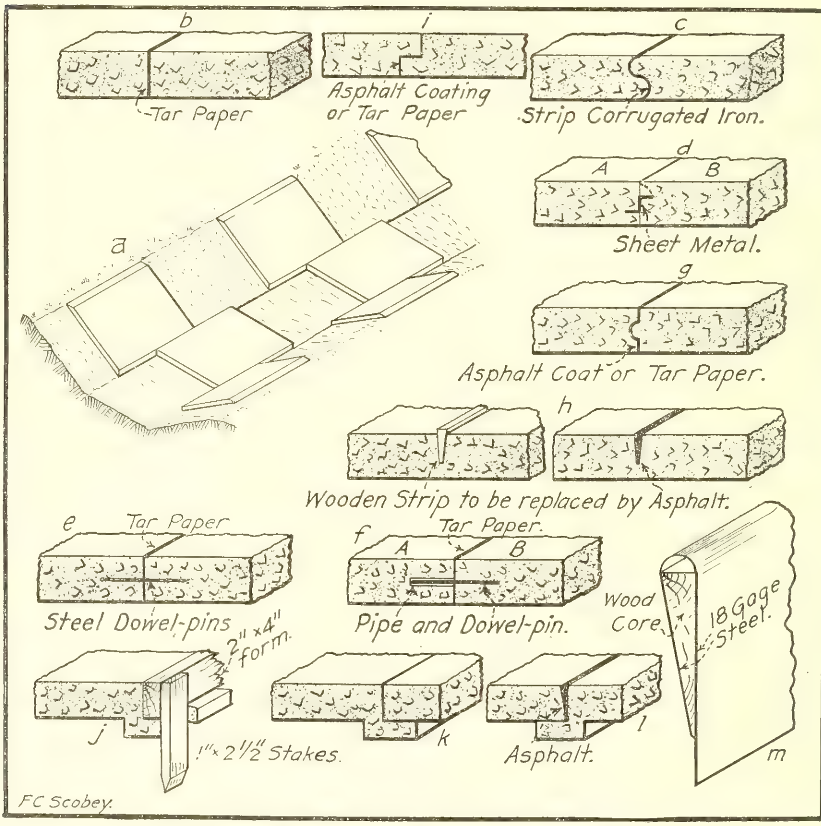


FIG. 3.—Typical joints for concrete-lined canals.

regarded as a separate slab, liable to be thrust upward by pressure from behind or to fall backward when the earthen support is removed. Both of these effects are quite probable, and may be seen in the lining of the New York Canal of the Payette-Boise project (fig. 4). Another defect is the difficulty experienced in filling the seam with any material which will render the joint water-tight, it being too narrow to calk.

(2) The abutting joint is frequently modified by introducing one or more plies of tar paper (fig. 3, *b*). While the paper provides for

extra expansion and renders the joint more impervious, it adds nothing to the bond between the sections.

FIG. 4.—A broken joint in concrete lining, New York Canal, Boise, Idaho.

(3) An interlocking device (fig. 3, *c*), consisting of a 4-inch strip of corrugated iron, was inserted in each joint of the lining of the North Side Twin Falls Canal, Idaho. If the metal strip is thickly

coated with asphalt before being inserted it may prevent leaks. The device likewise secures a fairly good bond.

(4) A pliable metal sheet protected from rust, of the form shown in figure 3, *d*, has also been used for such purposes. When section A is being laid the metal assumes the form of a right angle, the vertical part being placed against the form. Before section B is laid the upper portion of the vertical is bent down to a horizontal position, as shown.

(5) In the Ridenbaugh Canal of the Nampa and Meridian irrigation district, Idaho, tar paper was inserted between the abutting joints, which are spaced 16 feet 3 inches apart, and a good bond between the sections was secured by short ½-inch steel rods (fig. 3, *e*).

(6) To overcome the objection of projecting rods in laying by the method just described, the plan of bonding shown in figure 3, *f*, has been devised. A socket is formed in section A by means of a short ½-inch pipe, and into this is inserted one end of a steel rod five-sixteenths inch in diameter and double the length of a pipe. This contrivance adapts the joint to the alternate method of laying, as illustrated in figure 3, *a*.

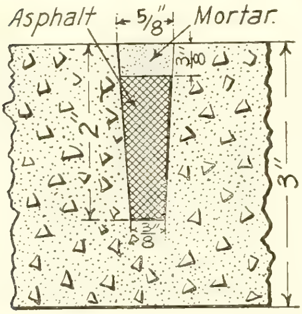


FIG. 5.—Sketch of joint used for concrete lining, Patterson Land & Water Co., Patterson, Cal.

(7) The form of joint used by the writer on the Snake Ravine retaining walls of the Turlock irrigation district of California is shown in figure 3, *g*. In laying the lining in alternate sections the joint with its concave surface may be coated with hot asphalt or lined with tar paper before the adjacent section is laid.

(8) In lining the Davis and Weber Counties Canal in Utah, a thin strip of wood coated with asphalt was placed in each joint and extended through about two-thirds the thickness of the lining. The specifications called for the withdrawal of these strips and the filling in of the spaces with hot asphalt, but this was not done. As a result, many of the wooden strips became loose and project more or less above the surface of the lining, thus retarding the flow of water. In other respects the joint has proved satisfactory. (See fig. 3, *h*.)

(9) A somewhat similar joint (fig. 5) was used by the engineers of the Patterson Land & Water Co. and the East Contra Costa Irrigation Co. On both canals, to which references are made elsewhere, the wooden strips were removed and the spaces filled with hot asphalt to within three-eighths inch of the surface, the remaining space being filled with cement mortar. When inspected by the writer during construction he questioned the advisability of so wide a joint, and was advised that a smaller joint could not well be filled with asphalt.

(10) Where conditions are adapted to its use, the type of joint shown in figure 3, *i*, possesses some advantages over those previously discussed. This is merely the carpenter's shiplap or half-timber joint applied to concrete. It provides for all the expansion necessary without weakening the lining by too wide a joint space. It also permits a certain amount of "creeping" in the section without misplacement and furnishes an excellent opportunity to secure a watertight joint by the use of an elastic material like asphalt.

(11) In adapting the shiplap joint to thin concrete linings a greater thickness of lining is used at each joint. The sections shown in *j*, *k*, *l*, and *m*, figure 3, represent this modification showing two joints and methods of construction, as designed by A. F. Parker for the lining of the Davis and Uinta Counties Canal in Utah.

CONSTRUCTION METHODS AND COST.

In submitting the following data an effort has been made to show as fully as possible what constitutes current practice throughout the West in the lining of old and new canals. The lack of space prevents taking up many of these features in detail, but it has been the aim to select representative work in the various localities and to point out not only the good features of such work but to call attention to doubtful practices in order to assist the engineer in the design and execution of similar construction elsewhere.

PATTERSON LAND & WATER CO., PATTERSON, CAL.

About three years ago a series of pumping plants was installed to raise water from the San Joaquin River to irrigate a tract of 14,000 acres, comprising the bulk of what is locally known as the Patterson ranch. To prevent the loss of water by seepage the canals of this system were lined with a 3-inch layer of concrete and finished with a ¼-inch plaster coat.

The main canal at the river end (Pl. II, fig. 1) has a bottom width of 7 feet, a vertical depth of 5½ feet, side slopes of 1½ to 1, and a capacity of about 110 second-feet. Its capacity is reduced at various points along its length, and at a distance of 2½ miles from the intake the bottom width is 4½ feet.

After the excavation of each division the main canal was filled with water and allowed to soak for from 6 to 9 days. It was then trimmed and lined in 12 foot sections. The gasoline-driven concrete mixer had a capacity of 75 cubic yards per day, which provided material to line 300 linear feet. The position of this mixer when operated and the methods employed in elevating the material and delivering the concrete are shown in Plate II, figure 2. The concrete used was a mixture of 1 part cement to 6 or 6½ parts of sand and gravel. The plaster coat was proportioned 1:2 cement and river sand.

EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

This enterprise, although much larger, is similar in design, purpose, and scope to that at Patterson. Mr. A. Kempkey, the engineer in charge, in writing of this project claims that some improvements have been introduced in the lining as planned over the lining used on the Patterson project. One of these is the insertion of two expansion joints at the toe of each slope and parallel to the canal axis. It is also proposed to apply the mortar coat by means of a cement gun, at an estimated cost of 1 cent per square foot of surface.

The expansion joint used on both projects is shown in detail in figure 5, page 60. It has given good satisfaction wherever used in both canal and reservoir lining. A medium grade of asphalt, applied warm enough to flow readily but not smoking hot, is considered best to fill the joints. In using this joint it is not necessary to place the lining in alternate sections, as a tapering strip of wood may be inserted between adjoining sections. These strips can be afterwards removed and the joints formed by pouring asphalt into the grooves and applying a ½-inch coat of plaster on top of the asphalt. Plate III, figure 1, shows the work of lining this canal in progress and in Plate III, figure 2, is shown a portion of the completed canal lining.

NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

This company lined 8,400 feet of its main canal to increase its capacity. The canal is carried for several hundred feet along a rough lava rock cliff and is 60 feet above low water in the river. The outer bank through this section is a concrete retaining wall. The remainder of the lined section is excavated almost wholly in solid lava. The grade varies from 0.001 in narrow places to 0.0002 and 0.00025 in the wider sections.

The canal was emptied October 10, 1909, and the work of preparing it for the concrete was commenced as soon as the channel had dried sufficiently. In places for several hundred feet from the headgates the canal bed was considerably below grade. The rock projecting into the canal section in the sides and bottom was blasted and smoothed, the low places being filled to subgrade with broken stone and puddled earth.

An 8-inch thickness of concrete was applied to the sides of the rock sections and a 6-inch thickness to the bottom. The sides of the rougher rock sections were riprapped to secure a better alignment and to save concrete. Cavities and large irregularities were back-filled with stones and puddled earth. It seems to the writer that the 6-inch thickness laid on the bottom of rock sections might have been reduced to 3 or 4 inches if the bed had been better prepared by the placing of finely crushed stone, compressing this material by rolling to secure an even surface and uniform grade, as is done in macadamized road construction.

The concrete was composed of a 1:3:6 cement, sand, and crushed stone mixture, but whenever a well-graded crushed stone could be secured sand was omitted and the concrete was made of 1 part cement to 6 parts crushed stone from which all particles over $1\frac{1}{2}$ inches in diameter had been excluded.

In earth sections the lining of the sides and bottom was 4 inches thick and had side slopes of $1\frac{3}{4}$ to 1. Expansion joints of corrugated iron were inserted every 16 to 20 feet along the sides and bottom except in the bottom of the rock sections. These joints consisted of pieces of corrugated iron cut into strips 4 inches wide containing $1\frac{1}{2}$ corrugations, these being designed to lock the edges of adjacent sections and to prevent slipping. (See fig. 3, *c*.)

The side walls in the rock sections were supposed to have a slope of 1 to 4; but in many places where this would have necessitated the blasting of large amounts of rock, walls were made almost vertical. Heavy, collapsible forms of 2-inch lumber were used in placing concrete for the walls which approached the vertical. The concrete was wheeled directly from the mixers and spread in uniform layers 4 inches thick over the bottom and on the sides of the easier slopes in earth sections. Concrete placed within forms made of 4 by 4 inch lumber was compacted by tamping and finished by working 24-foot floats made of 2 by 6 inch timbers back and forth over the upper surface of the forms. Sixty cubic yards of concrete per day were sometimes laid in this way by one gang working under favorable conditions. The sides and slopes were finished with a coat of cement mortar whenever the surface was rough enough to warrant it.

The unusually high cost of this work was largely due to the difficulty of preparing the rock cut for the lining and to the absence of sand and gravel, which made it necessary to crush rock for the concrete. However, a greater factor than either of these was the added expense due to the necessity of prosecuting the work during severe winter weather. To do this the canal was roofed over for a distance of 2,000 feet and the inclosed space warmed by specially constructed heaters, using sagebrush for fuel. The nature of the temporary roof and the method of heating are shown in Plate IV, figures 1 and 2. The cost of labor and material was as follows:

Cost of labor and materials for lining Twin Falls North Side Canal.

Laborers, per day of 10 hours	\$2. 50
Drillers, per day of 10 hours	2. 75–3. 00
Engineers (steam), per day	3. 00–4. 00
Man and team, per day	5. 00
Coal per ton, f. o. b. Milner	6. 50
Cement per barrel, f. o. b. Milner	2. 59–2. 89
Cost of crushing rock, per cubic yard	1. 10
Cost of labor for placing concrete, per cubic yard	2. 75

Complete cost of material, mixing and placing concrete for form work only, per cubic yard	$8.50
Same without forms	7.50
Cost of rock excavation (light cuts from 0.4 to 2 feet), per cubic yard	5.00
Cost of placing riprap 1 foot thick, per cubic yard	2.00
Total cost of preparing 8,400 linear feet of canal for concrete	75,000.00
Gross cost of lining 8,400 linear feet of canal	200,000.00
Average cost of concrete, per cubic yard	8.00

MAIN SOUTH SIDE, OR NEW YORK CANAL, UNITED STATES RECLAMATION SERVICE, BOISE, IDAHO.

This canal is designed essentially to carry flood water from a point on the Boise River 9 miles above Boise to the Deer Flat reservoir, a

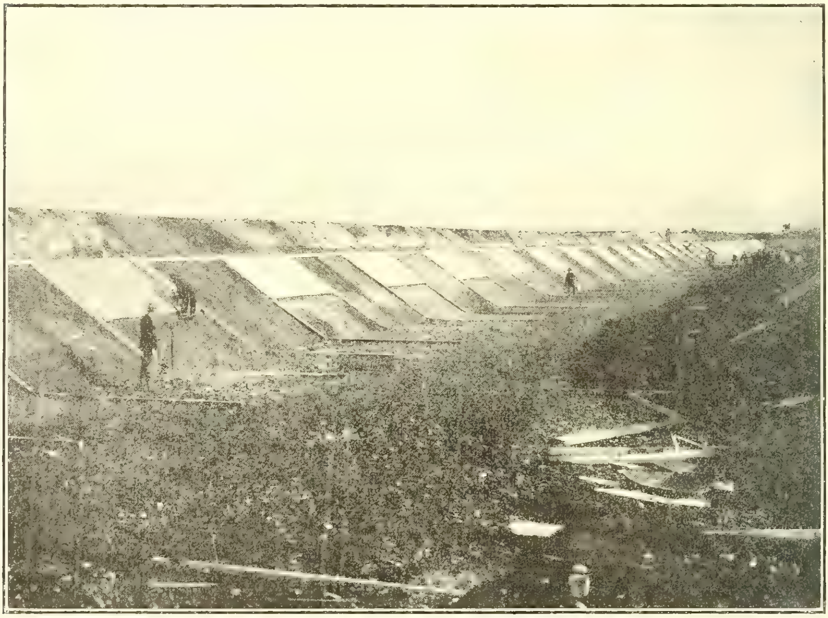


FIG. 6.—Showing method of setting forms on slopes for placing concrete lining in Main South Side, or New York Canal, U. S. Reclamation Service, Boise, Idaho.

distance of 36 miles. Seventy thousand acres of land is also watered from the canal before the reservoir is reached. About $6\frac{1}{2}$ miles of the canal was lined to prevent seepage, increase the carrying capacity, and for the safety of sidehill sections where breaks frequently occurred.

The canal is an old one, originally built with side slopes of $1\frac{1}{2}$ to 1, but the change and filling up of the section common to old canals necessitated considerable preliminary work in the removal of very gravelly earth and in shaping the sides before the concrete could be laid. The lined section has a grade of 0.00025 to 0.00032 and slopes of $1\frac{1}{2}$ to 1. Forms of 4 by 4 inch lumber were placed upon the slopes and aligned, as may be seen in figure 6, after which the surface

FIG. 1.—PORTION OF LINED CANAL, PATTERSON LAND & WATER CO., PATTERSON, CAL.

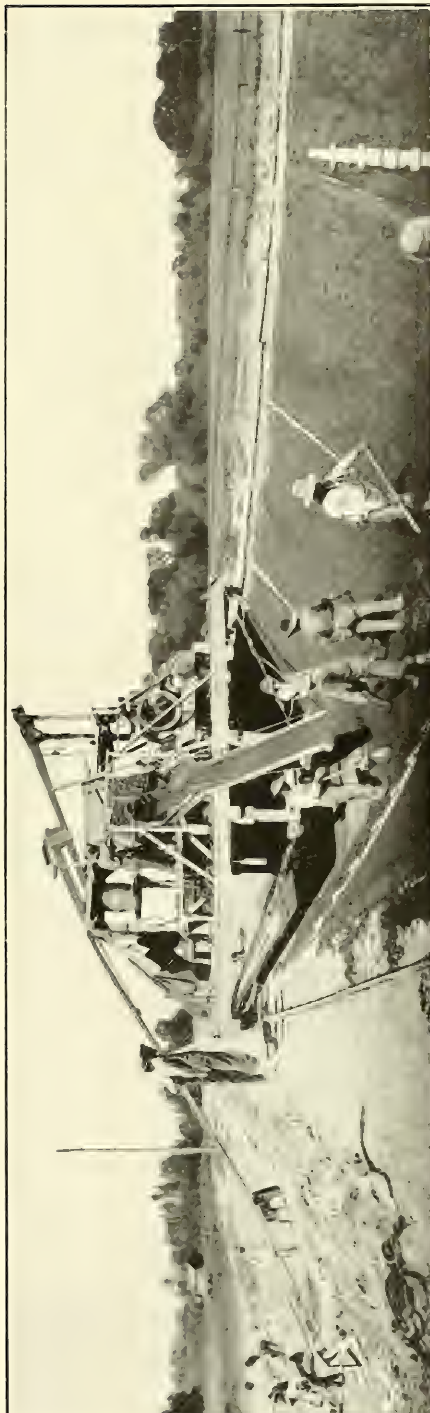


FIG. 2.—CONSTRUCTING CONCRETE LINING IN MAIN CANAL, PATTERSON LAND & WATER CO., PATTERSON, CAL.

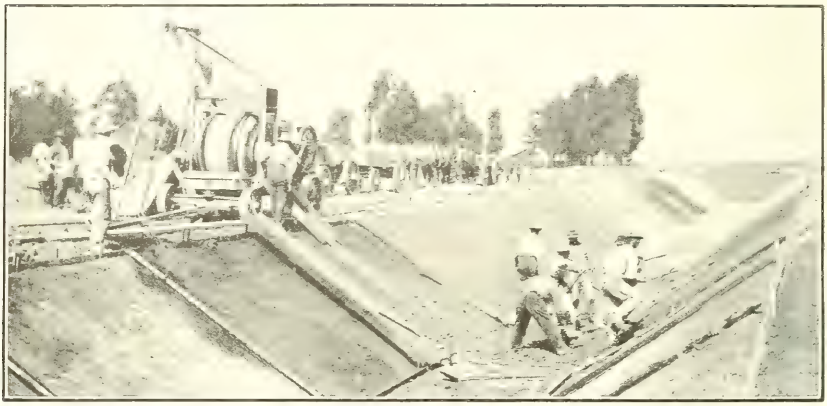


FIG. 1.—LAYING CONCRETE LINING IN CANAL OF EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

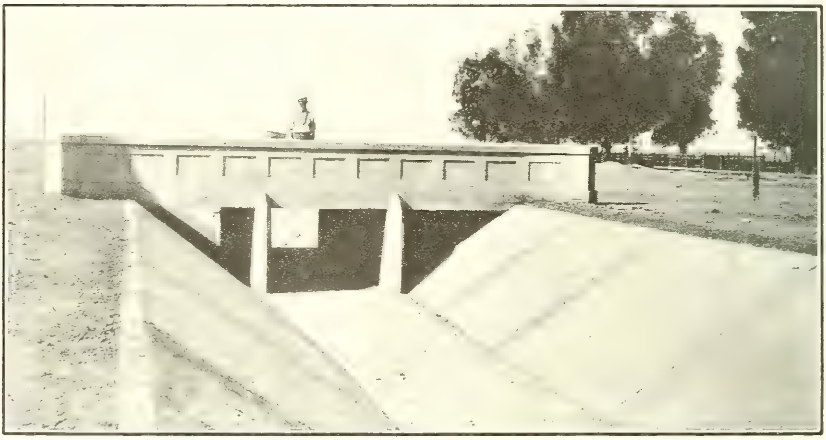


FIG. 2.—CONCRETE-LINED CANAL OF THE EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

FIG. 1.—COVERING USED FOR CANAL AND METHOD OF HEATING WHEN CONCRETE LINING WAS BEING CONSTRUCTED, NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

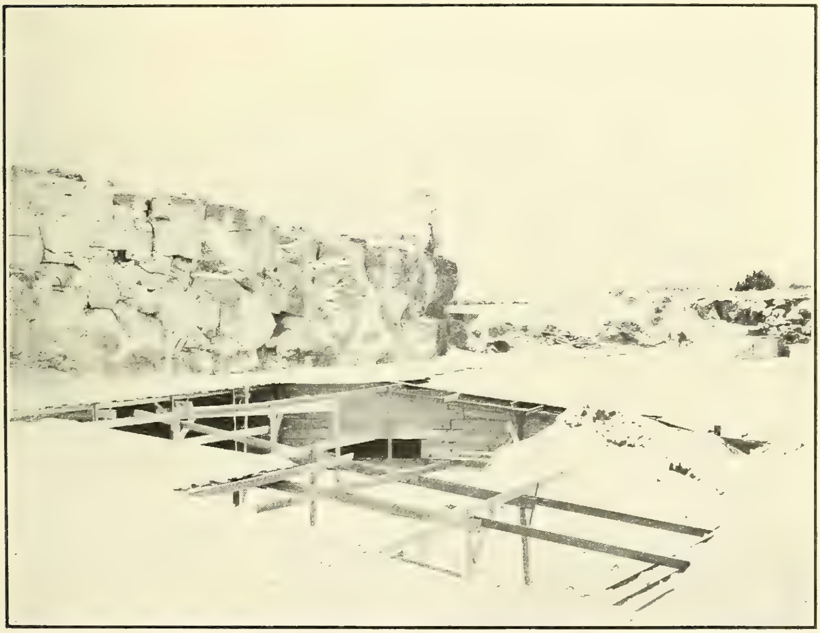


FIG. 2.—OUTSIDE VIEW OF COVERING USED FOR CANAL WHEN CONCRETE LINING WAS BEING CONSTRUCTED, NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

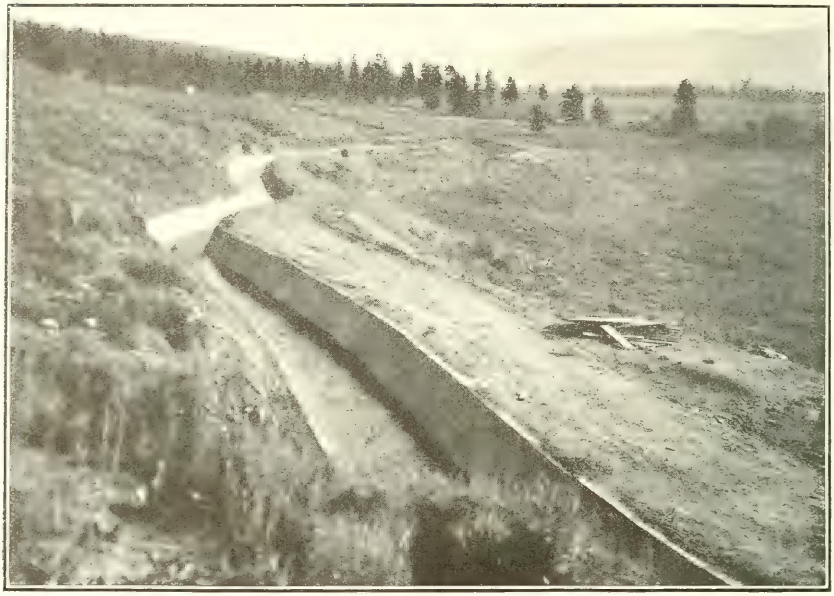


FIG. 1.—CONCRETE-LINED CANAL FOLLOWING THE LOCATION OF AN OLD CHANNEL, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

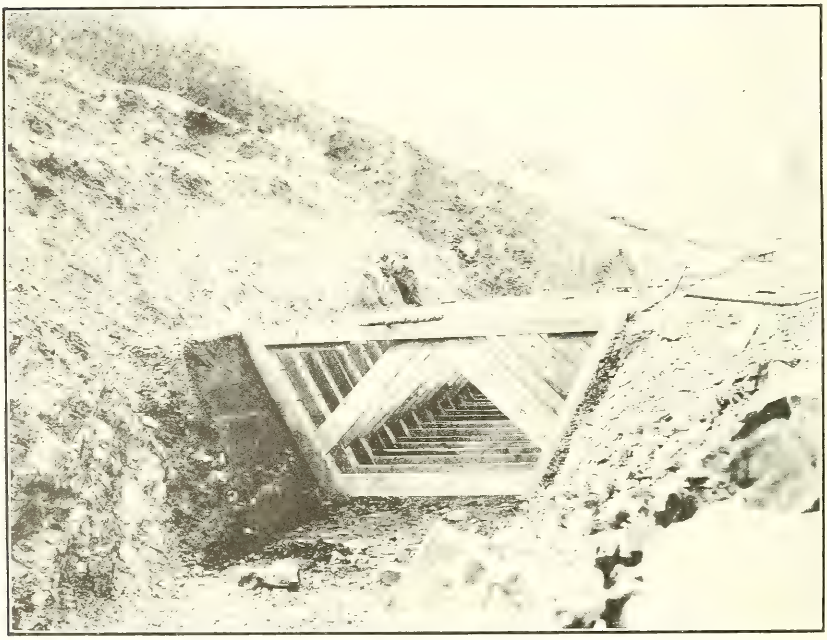


FIG. 2.—FORMS USED FOR BACKFILLING WITH PUDDLED EARTH TO PREPARE CANAL FOR CONCRETE LINING, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

between the forms was smoothed and thoroughly hand compacted. A uniform layer of concrete 4 inches thick was then applied.

After heavy stripping, a good natural mixture of sand and gravel was secured adjacent to the canal. This was hauled by slip scrapers up a runway and dumped into the mixers, which were placed high enough to permit discharging the concrete directly into one-horse carts. The concrete was a 1:3:6 mixture of Portland cement, sand, and gravel. It was laid in sections measuring 8 by 16 feet on the slopes and 8 by 16 or 16 by 16 feet on the bottom. The lining was laid in alternate sections to make room for the workmen, and the upper sections were usually the first completed. As soon as the concrete of the first sections had set, the forms were removed and the intermediate sections filled in. Expansion joints of one thickness of tar paper were used between sections in part of the work.

After being dumped from the carts, the concrete was worked down and later smoothed by drawing long floats made of 2 by 6 inch timbers back and forth across the forms. In order to get a smooth face, the surface was painted with a 1 to 2 finishing coat of cement mortar as soon as the concrete was placed and set. The lining was kept wet by sprinkling for a period of seven days after being laid. It was protected from nightly freezes during the early part of the work by covering with a layer of straw, and during some freezing weather in the latter part of the work some concrete was laid under large tents heated by stoves.

Some of the cost items are as follows:

Cost of lining New York Canal.

Preparing canal section for lining, per linear foot, approximately	$2.80
Hauling gravel to mixers, per cubic yard	1.14
Mixing and placing concrete, per cubic yard	2.20
Total cost of concrete, including cement, per cubic yard	7.70
Total cost of concrete in place, per lineal foot	9.64
Cement per barrel, f. o. b. Boise	$2.27–2.50
Common labor, per day	2.50
Man and team, per day	5.00

FRUITLAND IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

This company has lined some 6 miles of its main canal. The writer examined the lined portion of this canal in the summer of 1912 and found it in good condition. The upper bank is quite generally in excavation and the lower bank is partly in excavation and partly in fill. There appear to be more curves than the nature of the ground warrants, but A. E. Meighans, the company engineer, stated that the lined canal follows an old location for a ditch built before this company acquired the property. (Pl. V, fig. 1.)

Some slight injury to the lining has resulted from earth settlement. Lining the sides of the curves required the use of short forms, which were also used on tangents, resulting in a much larger number of joints on the straight portions than good practice warrants. The joints were spaced 6 feet apart, and an attempt has been made to cover the seams with a coating of cement mortar. It is claimed, however, that these will eventually become filled with sediment, but the daily and seasonal contraction and expansion usually tend to enlarge rather than to decrease their width.

Plate V, figure 2, shows the forms used for back-filling with puddled earth to prepare this canal for concrete lining. In Plate VI, figures 1 and 2, these forms have been removed and the channel is ready to receive the forms used in placing the concrete, as shown in Plate V, figure 2. Additional information on construction methods used with other useful data are to be found elsewhere.[1]

NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

During the winter of 1910–11 this company lined 22,500 feet of ditches on the "Highlands" at Kennewick to eliminate heavy seepage losses. The soil through which these ditches are built is principally a fine sandy loam overlying gravel at a depth of 18 inches to 2 feet.

One ditch 10,800 feet long, 3 feet wide on the bottom, with side slopes of ½ to 1 and a vertical depth of 26 inches, is designed to carry 18 second-feet. Another ditch having in part a bottom width of 3½ feet, side slopes of ½ to 1, and a vertical depth of 19½ inches is designed to carry 14 second-feet. This ditch is reduced to a bottom width of 2½ feet, but with the same side slopes and depth as the upper part. The concrete used was a 1:3:4 mixture of cement, sand, and crushed rock.

In preparation for lining, center grade stakes were set and the bottom of the ditch brought to grade. Scantlings 2 by 4 inches were then placed across the bottom of the ditch at 12-foot intervals at right angles to the center line and flush with the subgrade. Three forms 12 feet long (Pl. VII, fig. 1) were then set in the ditch on the cross strips and centered. Earth was shoveled and tamped behind the forms to secure the desired section. There were 14 men in a crew on this work.

After the earth sections were prepared in this way, 2 by 2 inch screeds (Pl. VII, fig. 2) were placed at intervals of 5 feet 8 inches and upon them forms 6 feet long were set on every other space. The concrete was mixed with a one-third yard mixer, wheeled to place and dumped on planks laid on top of the forms. It was then shoveled behind the forms and lightly tamped. Strips of sheet iron were inserted behind the forms to protect the slope while the concrete was being put in and also to prevent a too rapid loss of water from the mixture by its contact with the drier earth. These

[1] Brit. Columbia Dept. Agr. Bul. 44 (1912).

strips were raised as the filling progressed. Two crews of 5 men each placed the concrete behind the forms, 2 men wheeled to each crew, and about 5 men were employed to move forms, etc. About 6 men were in the mixing crew and 2 others plastered rough places in the lining.

Water kept in the finished ditch a few hundred feet in the rear of the work (Pl. VII, fig. 3), was pumped ahead to the mixer with a small gasoline engine.

The engineer stated that in one hour a crew could place about six sections, or 34 lineal feet, of the lining in the ditch having a 3-foot bottom.

On some of this work done during freezing weather, canvas covers were placed over the ditch. Under these covers iron pipes were laid through which steam was run from a steam boiler during the night.

Rock gathered from various places within the locality was crushed and hauled from 1 to 1½ miles. Six men collected the rock, 4 men operated the crusher, and about 7 teams hauled the crushed rock to the place of use. The cost of the crushed rock was not obtainable, but other items of expense were as follows:

Cost of labor and materials for lining Northern Pacific Canal.

Cement per barrel delivered at works, approximately	$3.00
Sand delivered by contract, per cubic yard	1.75
Laborers per hour, without board	.25
Teams per hour, without feed	.35

TRUCKEE-CARSON PROJECT, NEVADA.

A part of the main lower Truckee Canal constructed in 1904 and 1905 by the United States Reclamation Service was lined with concrete. Much of this lining was placed without the use of expansion and contraction joints. In November, 1911, about six years after the lining was completed, Mr. F. L. Peterson, irrigation engineer of this office, made a careful examination of the lined portions of this canal to determine if possible the effect produced by the lack of joints. Plate VIII, figure 1, is a general view of the lined canal opposite the railroad siding at Gilpin, Nev. Here the canal is excavated for the most part in solid rock and lined with 4 inches of concrete. In the same plate are shown fractures in the lining after a thin mortar coating had been placed over the seams. Plate VIII, figures 2 and 3, gives a closer view of two of the fractures, the latter one of which has been repaired.

The general specifications for the concrete used on this work provided:

The concrete to be used on all the structures and tunnels on this canal will be composed of Portland cement, sand, and gravel or broken stone, in the proportion of

1 barrel of cement to 7 full barrels of the same size of aggregates when mixed together. If broken stone is used, it must be hard, clean, and heavy, having at least a specific gravity of 2 and screened into three different sizes. None of the gravel is to exceed 2 inches in diameter. The mixture of such sizes will be in the proportion determined by the engineer. All of the rock must be of such size that it will pass through a screen with a 2-inch square mesh.

The seam shown in Plate IX, figure 1, is typical of many such seen in canal lining in that it gradually diminishes in width from the top to the bottom of the side lining. Plate IX, figure 2, shows a fracture extending not only through the concrete but also through a diabase rock some 14 inches long and 4 to 6 inches thick which was embedded in the concrete. The natural cleavage of this rock, it may be observed, was nearly at right angles to the rupture as made by the contraction of the concrete.

The placing of the concrete lining against the uneven rock surface served to anchor the lining and prevent contraction, and this same foundation condition doubtless added much to the strength of the lining as a whole. Notwithstanding this fact, however, ruptures have occurred at intervals of 28 feet or more throughout the lining. The seams created by these ruptures varied in width from one-twelfth to one-half inch or more at a time when the temperature of the air was 50° and that of the water in the canal was 42° F.

LOWER YAKIMA IRRIGATION CO., RICHLAND, WASH.

The canal of this company parallels the Yakima River for several miles, where the earth sections run mainly through coarse gravel, bowlders, or shattered basaltic rock. The remainder of the system is very largely built through sand. In the unlined channel the seepage losses were excessive, and through the sand it was also difficult to maintain the ditch owing to its tendency to fill up both by drifting and on account of the flat side slopes which the sand naturally assumed under the action of water. The lining was intended, therefore, not only to reduce the loss of water but to increase the carrying capacity of the ditch and render it more stable and easy to maintain. About 5 miles of the ditch was lined in 1910. The company furnished all materials used and prepared the channel for lining, but the other work was done by contract.

In preparing the ditch, center stakes were set about 1½ inches above grade, to which the excavating was roughly done with teams and scrapers. At intervals of about 25 feet along the bottom of the side slopes stakes were set to grade, and from these the top slope stakes were set by the use of a slope triangle. Nails were driven into the grade stakes and chalk lines were stretched on them parallel to the ditch. Trimming to these lines was done then with square-pointed shovels and the slopes and bottom scraped to smooth sur-

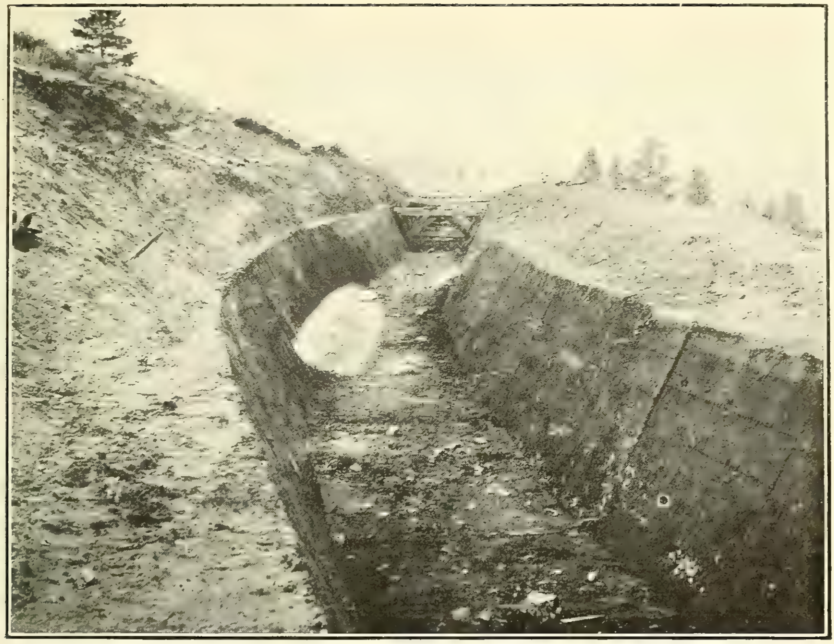


FIG. 1.—EARTHEN CANAL PREPARED FOR CONCRETE LINING, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

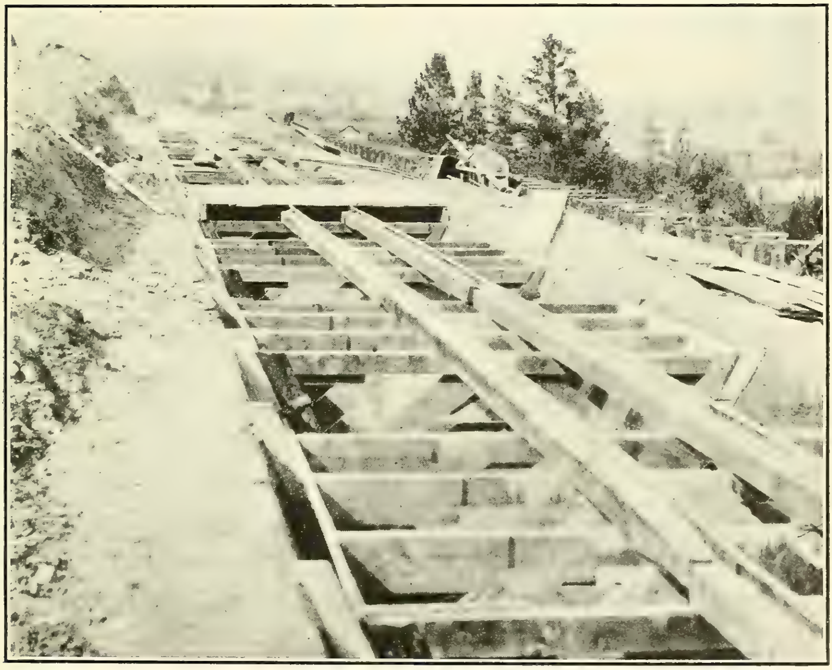


FIG. 2.—FORMS PLACED TO RECEIVE CONCRETE, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

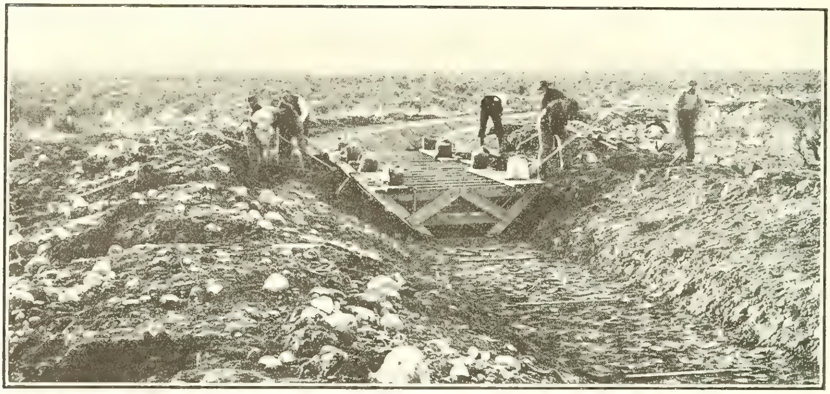


FIG. 1.—PREPARING EARTHEN CANAL SECTIONS FOR CONCRETE LINING, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

FIG. 2.—SETTING FORMS PREPARATORY TO CONSTRUCTION OF CONCRETE LINING, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

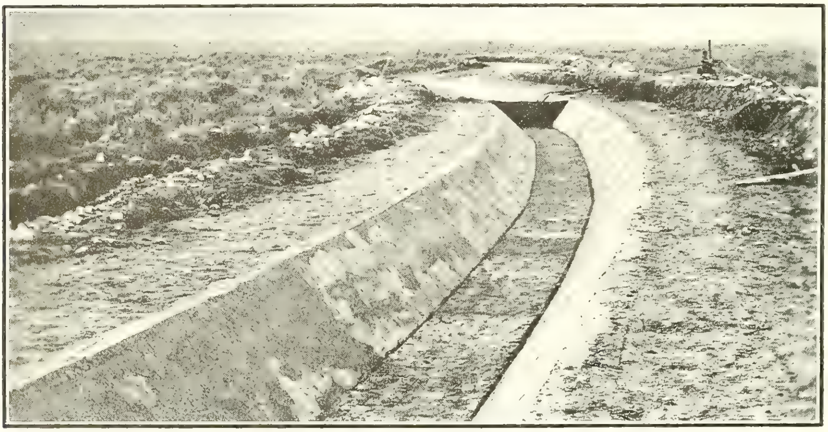


FIG. 3.—SECTION OF CONCRETE-LINED CANAL, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

FIG. 1.—CONCRETE LINING IN TRUCKEE-CARSON CANAL, AT GILPIN, NEV.

FIG. 2.—SHOWING FRACTURES IN CONCRETE LINING OF TRUCKEE-CARSON CANAL, NEV.

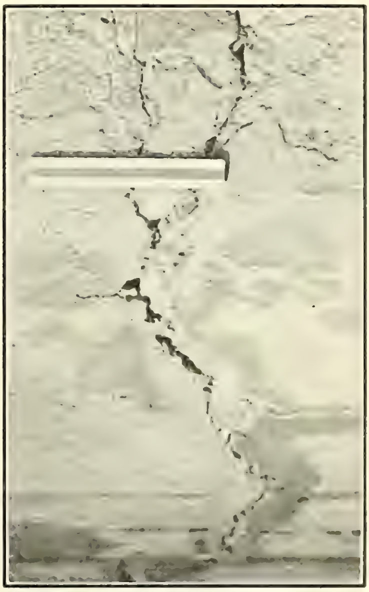


FIG. 3.—SHOWING FRACTURES IN CONCRETE LINING OF TRUCKEE-CARSON CANAL, NEV.

FIG. 1.—TYPICAL CRACK IN CONCRETE LINING, TRUCKEE-CARSON CANAL, NEV.

FIG. 2.—CRACK IN CONCRETE LINING EXTENDING THROUGH DIABASE ROCK, TRUCKEE-CARSON CANAL, NEV.

faces with straight-edges. The sides and bottom were tamped lightly with wooden tampers and sprinkled before the lining was applied. The section lined has a bottom width of 11½ feet, side slopes of 1½ to 1, and a wetted perimeter of 26½ feet.

The three mixers used were operated on planks in the bottom of the ditch in advance of the work. With each mixer there was a crew of about 25 men and in addition a finishing crew of 5 or 6 men to dress the earth surfaces immediately ahead of the mixer. One rock crusher was also operated, the crushed rock being hauled an average of 2 miles. Most of the sand was procured from pits along the line of the canal and was used without screening. The lining was laid in 8-foot sections 1¾ inches thick, with strips of building paper in the joints between the sections. Four hundred feet of lining was considered a good day's work for a crew.

A 1:3:4 mixture of concrete was used for most of the lining, but on one section a 1:4 mortar applied 1 inch thick was considered just as good as the thicker lining of concrete, besides being much easier to apply.

The lining in gravel sections leaked considerably the first season, presumably because allowed to dry too rapidly on account of lack of water for keeping it moist after laying. In work that was done the following year this difficulty was obviated by allowing a small amount of water to flow in the ditch soon after lining, using check dams to prevent its interference with construction. Men wearing rubber boots then waded along and with shovels or buckets threw water upon the side slopes at frequent intervals to keep the concrete wet while setting. Where lining had been placed on moistened sand, the results were better than in the sections through gravel, there being no perceptible leakage. Conditions in the gravel portion improved with the first year's use of the lined section, after which the seepage was considerably lessened.

The various items of cost secured are as follows:

Cost of lining canal of Lower Yakima Irrigation Co.

Laborers per day of 10 hours, without board	$2.50
Man and team per day, without board	4.50
Contract price per square foot for mixing and laying concrete	.025
Cement per barrel [1]	3.10
Sand per cubic yard, approximately	.50
Total cost of lining, per square foot	.065
Total cost of lining	9,064.49

During February and March, 1911, the company placed additional lining, using practically the same methods above described, except

[1] This does not include an 8-mile haul over heavy roads.

that all work was done by force account. The prices for labor and material indicate that the work was done considerably cheaper than in the previous year. Laborers were procured for $2 per day without board and men with teams for $4 per day each. Cement cost $2.95 per barrel delivered at the work.

BELGO-CANADIAN FRUIT LANDS, KELOWNA, BRITISH COLUMBIA.

About 3,000 feet of this company's main canal, 11 miles long, and about 4 miles of its lateral ditches have been recently lined with concrete to prevent seepage losses in a porous soil. On the main canal a 3-inch thickness of lining has been used for a finished section having a bottom width of 3.5 feet, depth 3.75 feet, and side slopes of ½ to 1. Lateral linings are 2½ to 3 inches thick on slopes, with a 3-inch thickness on bottoms which vary in width from 9 inches to 2 feet.

After excavating the channel to be lined, a drain filled with loose rock or gravel was made beneath the bed. Cross drains from this through the lower bank were placed at 500-foot intervals. The forms shown in figure 7 were then set and bolted together. Galvanized-iron plates placed outside the forms were spaced with pieces of lumber, and after the earth was back-filled and tamped behind the plates concrete was poured between them and the forms. The galvanized plates and spacing pieces were withdrawn as the space was filled with concrete. The bottom of the ditch was then floated in and the edges smoothed, using for this purpose the excess concrete which had passed over the forms. The forms were left in place 48 hours.

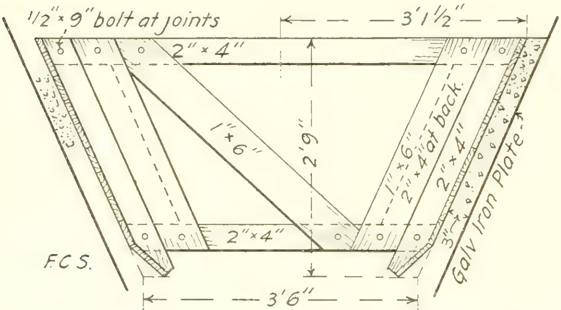


FIG. 7.—Section of form used for placing concrete lining, Belgo-Canadian fruit lands, Kelowna, British Columbia.

Curves were made by using special short forms having the outer edge superelevated ½ to 1 inch according to the degree of curvature. In placing the concrete around sharp curves, special galvanized plates were used to close the gap at the outer edge of the forms.

No cost data could be secured on the lining of the main canal. The cost of lining laterals per square foot and exclusive of excavation varied from $0.118 in the larger to $0.142 in the smaller ones. These costs include excavation, back-filling, rock drains, and supervision. The work was done late in the fall when protection against frost increased the cost. Cement cost $3.75 per barrel delivered, common labor $2.75 per day, and skilled labor $4 per day.

TUCSON FARMS CO., TUCSON, ARIZ.

The water for this project is obtained by pumping from numerous wells. During the winter and spring of 1912–13 a reinforced concrete lining was placed in about $2\frac{1}{2}$ miles of the new main canal for the prevention of seepage losses through a sandy and gravelly soil.

The canal has a trapezoidal cross section entirely in excavation and as lined is capable of carrying a 2.9-foot depth of water. The bottom width ranges from 2 to $4\frac{3}{4}$ feet and the side slopes are 1 to 1. The greater part of the concrete used in this construction is a 1:4 :4 mixture and the lining is 3 inches thick throughout.

In grading the channel for lining, a framed template was used to get a true section. The reinforcement is made of round steel bars intersecting at right angles and wired together. Four longitudinal bars, $\frac{5}{16}$-inch diameter, were placed one on each side of the bottom for the lining floor and one on each side near the top of the side walls. Then at right angles to these, as stated, $\frac{1}{4}$-inch crossbars were spaced 12 inches apart. Each crossbar was continuous and extended from the top of the lining on one side through the lining to the top of it on the opposite side of the canal. When it was not possible to obtain the $\frac{1}{4}$-inch bars, $\frac{5}{16}$-inch bars were substituted and spaced 18 inches apart.

Wooden-framed forms built in 12-foot sections were then set in position over the steel reinforcement, blocked to place, and the adjoining ends bolted together. Then $\frac{1}{8}$-inch steel backing plates, 2 feet wide and long enough to reach to the bottom of the earth section, were slipped behind the forms and under the reinforcement. Before placing the concrete, wooden spreader-strips 2 by 3 inches were set between the wooden forms and the backing plates. Each spreader contained a staple driven almost full length into its side near the bottom, and in setting the spreader the staple loop was slipped over the end of the crossbar and the spreader was then slid into position. In this way the bar was carefully held in position while the concrete was being placed in the forms. A spreader was set beside each crossbar, and as the concrete for the side lining was tamped and puddled into place the spreaders were gradually removed, leaving the crossbars firmly embedded in the concrete. The steel plates likewise were withdrawn as the walls were built up. When the side forms were filled with concrete to within 3 inches of the top, the longitudinal bars were placed and wired to the crossbars. The remaining concrete was then placed and smoothed with an edging trowel.

Expansion joints were provided by setting 1 by 3 inch wooden strips in the middle of each form in the same manner as the spreaders, except that no staples were used and the joint strips were not removed afterwards. To keep them in position while concrete was being deposited, each one was lightly nailed to the side of the form, and before the latter was removed the nails were withdrawn.

The forms were left intact for a period of 8 hours at least, and they usually remained undisturbed over night during a period of 14 to 20 hours. After their removal any defects in the wall surface were "picked" out and the cavities smoothly plastered with a 1:1½ or 2 cement mortar.

The canal bottom was then carefully cleared of litter, its surface smoothed, and solidly tamped. All reinforcement bars that may have become bent were straightened. The bottom piece of the expansion joint was fitted to the two side pieces and its top carefully laid to grade. (Pl. X, fig. 1.) The concrete for the floor lining was then tamped and puddled into place, and when it had reached the required thickness the surface was easily brought to grade and smoothed by the use of a straightedge resting on the bottom joint strips as guides.

The entire lining was kept wet by continual sprinkling during a period of three to five days. After this was discontinued a wash coat of neat cement mortar was applied to the surface with a brush. (Pl. X, fig. 2.)

A 1:4:4 mixture of concrete was used on all the work except for about 1,000 feet of bottom where there was excessive external water pressure. In this portion of the canal a 1:3.2:3.2 mixture was used. As a further protection in one very wet and miry place, additional reinforcement was used in the bottom. Extending over a length of about 5,000 feet of the largest canal section near the Santa Cruz River bed, "weep holes" were formed in the bottom to relieve external water pressure. Two-inch tapering plugs extending entirely through the lining floor were set in the freshly laid concrete and these plugs were later removed as soon as the concrete had set sufficiently to retain its shape. Two rows of these holes were made 2½ feet apart and spaced 4 feet longitudinally. During construction a considerable portion of the canal was drained. A line of 8-inch tiling was laid in the bottom and pumps attached thereto were installed at intervals of about 1,000 feet to withdraw the accumulated water.

The contractor received $12.50 per cubic yard for the finished concrete lining, using slab measurement. This included all costs except the original purchase price of the steel reinforcement. However, no excavation was included and the company paid extra for the wash coat. The contractor rented a rock crusher and delivered the rock. Sand was obtained from the river bed.

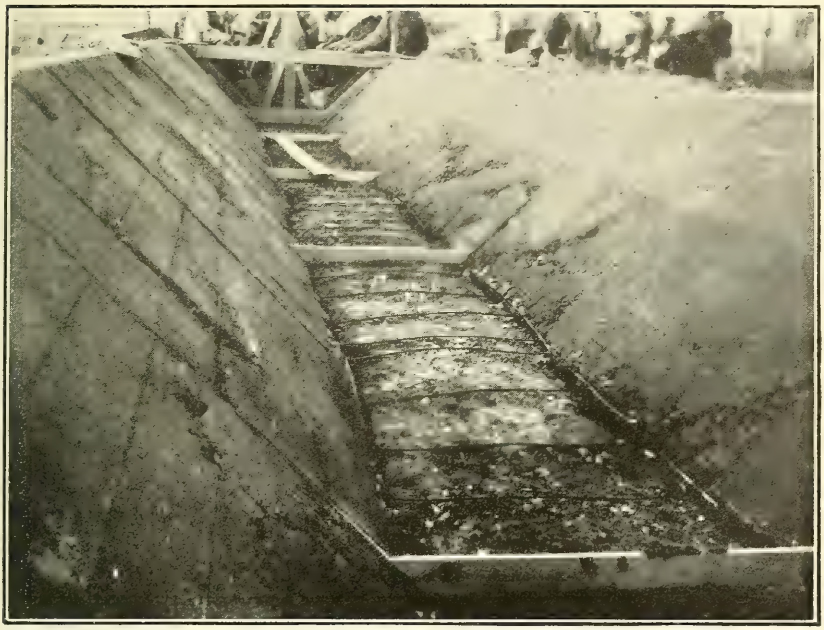


FIG. 1.—CONSTRUCTION REINFORCEMENT AND EXPANSION JOINT STRIPS USED IN CONCRETE LINING WORK, TUCSON FARMS CO., TUCSON, ARIZ.

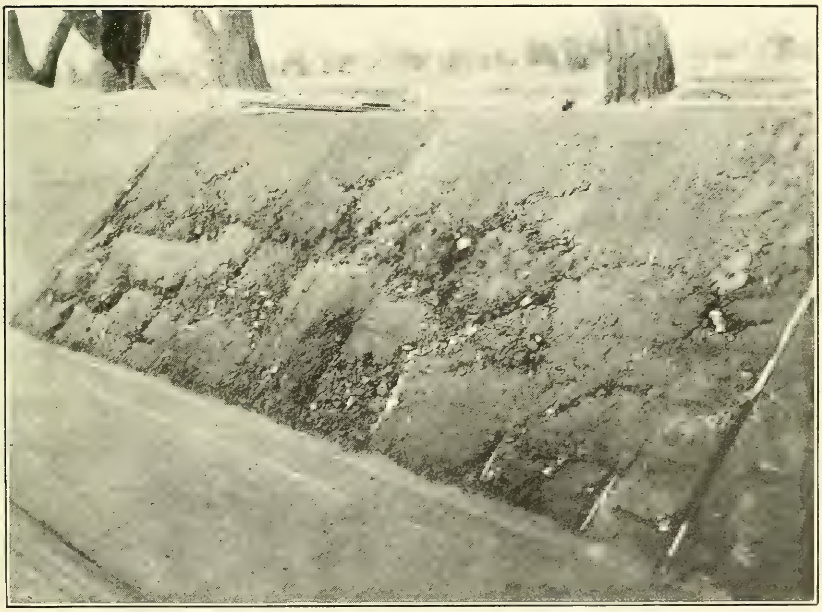


FIG. 2.—SHOWING EXPANSION JOINT STRIPS EMBEDDED IN CONCRETE LINING AND APPEARANCE OF CONCRETE SURFACE BEFORE APPLYING WASH COAT OF NEAT CEMENT MORTAR, TUCSON FARMS CO., TUCSON, ARIZ.

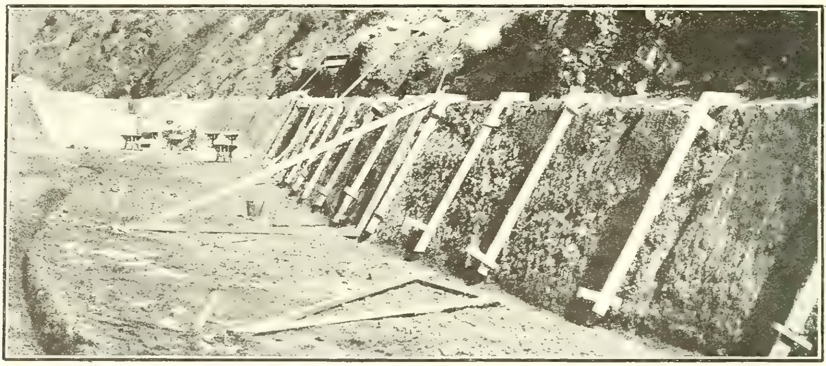


FIG. 1.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

FIG. 2.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

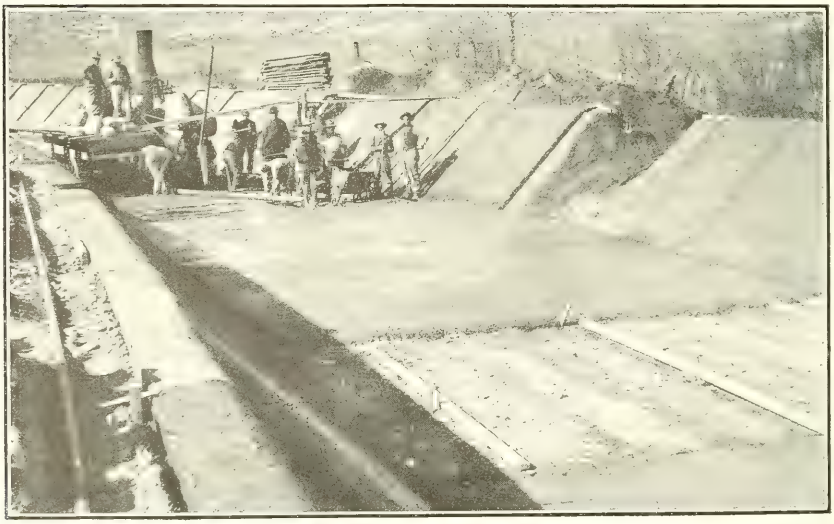
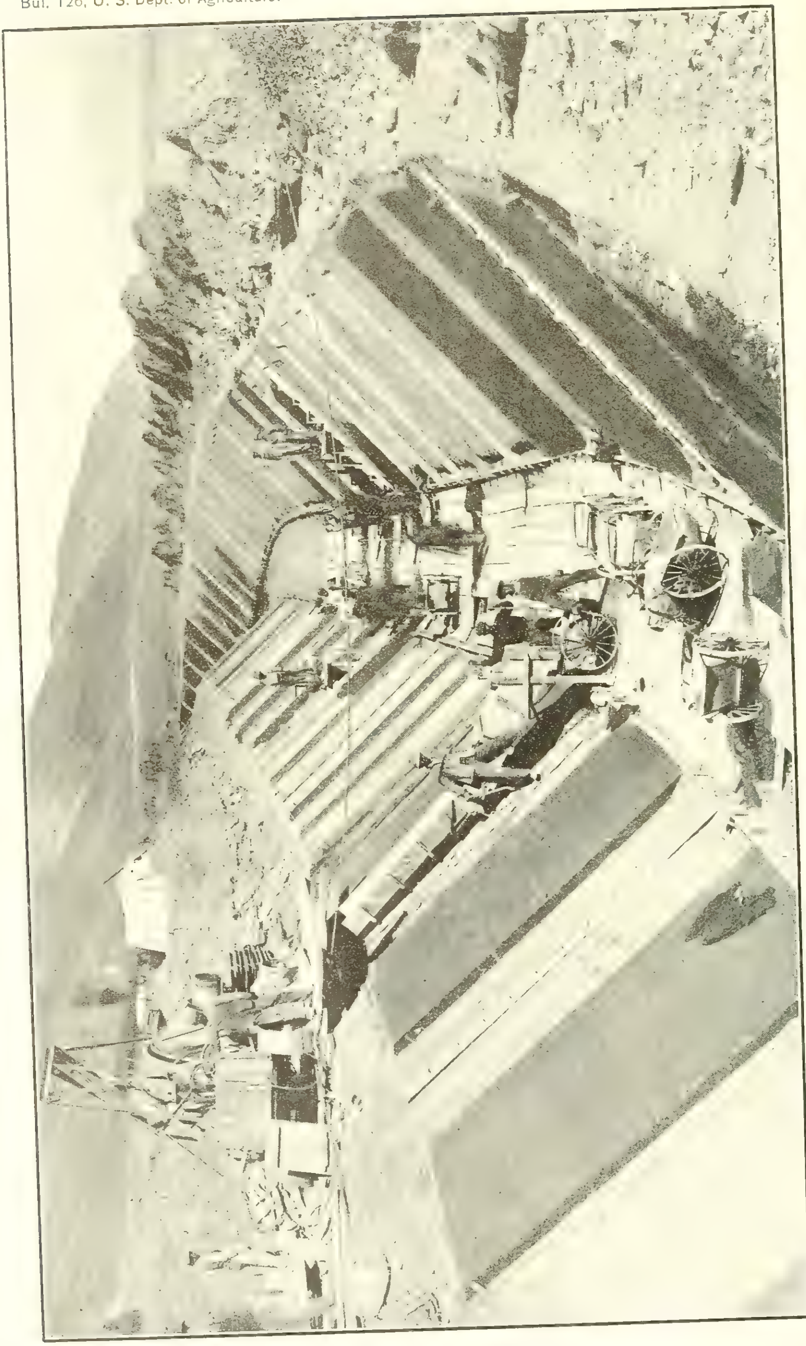


FIG. 3.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

FIG. 1.—SETTING FORMS PREPARATORY TO PLACING CONCRETE FOR LINING OPEN CHANNEL, LOS ANGELES AQUEDUCT, LOS ANGELES, CAL.

FIG. 2.—CONSTRUCTION OF CONCRETE LINING IN PROGRESS, LOS ANGELES AQUEDUCT.



METHODS USED IN CONSTRUCTION OF CONCRETE LINING FOR OPEN CHANNEL, LOS ANGELES AQUEDUCT.

All concrete was mixed by hand and transported in wheelbarrows. The work was performed with gangs of about 30 men, paid for a 9-hour day, as follows:

Wages of labor lining canal of Tucson Farms Co.

1 foreman	$4.00
Mixing boss and 2 plasterers	2.50
2 water boys	1.00
25 men	2.00

The gang was used in the following manner: Eight men on mixing board, 2 tampers, 2 men pulling plates and spreaders, 2 men setting forms and putting in expansion joints, 2 men laying steel reinforcement, 14 men transporting and depositing materials and concrete, finishing, screening sand, etc. The forms were usually all moved at one time and the whole force engaged on that work.

It required this gang 21 days to place lining in 3,000 feet of canal in dry excavation having a bottom width of 3 feet. The cost to the contractor was distributed as follows:

Contractor's cost of lining canal of Tucson Farms Co.

Labor, including the building of forms	$1,297.83
1,712 sacks of cement, at $0.81 each	1,386.72
232 cubic yards of rock, at $1.75 per cubic yard	406.00
232 cubic yards of sand, at $0.75 per cubic yard	174.00
Lumber in 15 sections of 12-foot forms, 3,900 feet b. m., at $30 per M	117.00
Lumber for expansion joints, 750 feet b. m., at $30 per M	22.50
Lumber for spreaders, runways, etc., 750 feet b. m., at $30 per M	22.50
Water purchased from the city of Tucson, 21 days at $2	42.00
Hauling steel reinforcement	10.00
Depreciation of plant, breakage of tools, etc	20.00
Office expenses and expenses of contractor and superintendent, amounting to about $2 per day for this gang, 21 days	42.00
Total	3,540.55

Computations made on the above basis for 298.9 cubic yards, the cost was $11.845 per cubic yard. However, there were in addition the following costs to the Tucson Farms Co.:

Additional cost of lining canal of Tucson Farms Co.

9,300 pounds of steel, at $0.04	$372.00
One coat of cement wash, 34,500 square feet, at $0.0025	86.25
Engineering, about 5 per cent	195.00
Total	653.50

On this basis the actual cost of the completed lining was $14.03 per cubic yard.

CENTRAL OREGON IRRIGATION CO., DESCHUTES, OREG.

The north canal of this company is concrete lined and diverts water from the Deschutes River a short distance below Bend, Oreg.

A 1:4:5 mixture of Portland cement, sand, and crushed rock was used on this work, the extra amount of sand being required to replace a considerable portion of the grout lost in the dry wall back of the lining. In preparation for lining the earth slopes, made $1\frac{1}{4}$ to 1 to avoid the necessity for forms, were finished to within 4 inches of the inner surface of the completed work. The rock slopes, however, were so badly broken that it was necessary to fill cavities with hand-laid dry walls (fig. 8).

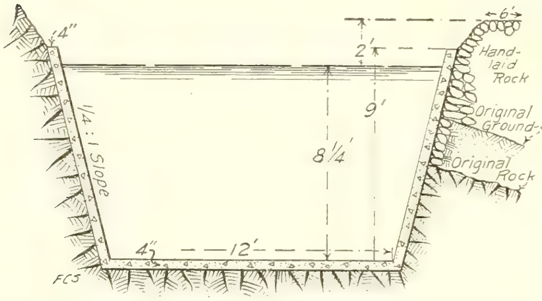


FIG. 8.—Section of concrete-lined canal in rock, Central Oregon Irrigation Co., Deschutes, Oreg.

Sectional forms made of shiplap were used repeatedly on the 6,300 lineal feet of canal through rock, but no forms were used on the 1,000 lineal feet of canal in earth. Expansion joints spaced at 12-foot intervals along the sides and bottom were made of $\frac{1}{4}$ by 4 inch wooden strips left in the finished concrete.

DAVIS & WEBER COUNTIES CANAL CO., OGDEN, UTAH.

During the years 1909 and 1910 this company enlarged and concrete lined $9\frac{1}{2}$ miles of its main canal. When the canal was built in the eighties it carried less than 100 second-feet, but its capacity has been increased from time to time until in 1909 it reached 200 second-feet. It has been difficult and expensive to maintain this canal owing to its location near the top of a steep hillside flanking the Weber River on the south. In July, 1893, the writer made a series of current meter measurements to determine the seepage losses throughout its length. The results showed a discharge at the headgate in Weber Canyon of 105.5 second-feet which in $9\frac{1}{2}$ miles seepage had reduced to $78\frac{1}{2}$ second-feet, representing a loss of 26 per cent of the total diversion from the river. This seepage water found its way into the steep hillside and during 25 years of its operation as an unlined canal produced an endless variety of slides throughout a length of 7 miles. In fact, the whole hillside for this distance seemed to have been subjected to a severe earthquake shock. Tracts, several acres in extent, traversed by the canal have been known to drop through a vertical height of 7 feet as a result of the action of seepage waters on the underlying materials, and buildings located more than 600 feet from the center line of the canal have been removed from the path of the slides.

In the fall of 1909 the company undertook to enlarge and concrete line this canal and to provide for a maximum carrying capacity of 725 second-feet and at the same time retain the old location. This entailed the removal of a heavy growth of willows skirting the banks and a large amount of excavation. On account of the unstable character of the materials and the steep cross slope of the hill on which the canal is located the lining of so large a channel presented unusual difficulties. These have been met, however, and the canal successfully operated for the past two seasons.

The canal was provided with drainage at various stretches along its length through the use of 6-inch drain tiling laid in longitudinal trenches 10 to 20 inches deep. At intervals of about 800 feet these drains were connected to cross drains of the same construction to convey the drainage waters to the outside of the outer canal bank.

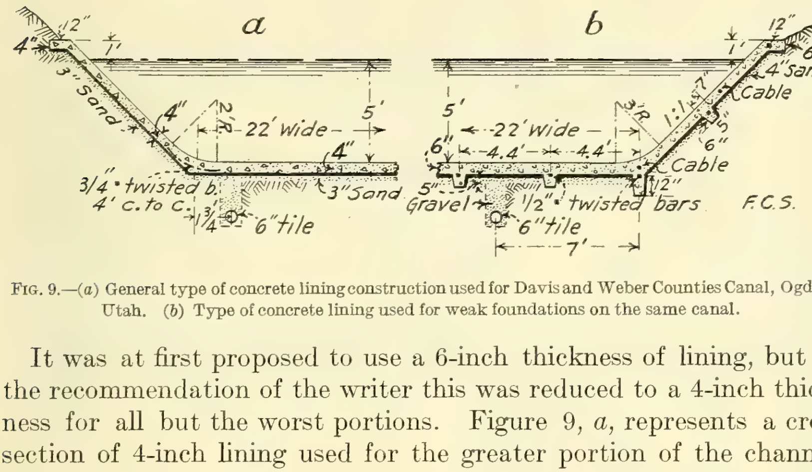


FIG. 9.—(*a*) General type of concrete lining construction used for Davis and Weber Counties Canal, Ogden, Utah. (*b*) Type of concrete lining used for weak foundations on the same canal.

It was at first proposed to use a 6-inch thickness of lining, but on the recommendation of the writer this was reduced to a 4-inch thickness for all but the worst portions. Figure 9, *a*, represents a cross section of 4-inch lining used for the greater portion of the channel. Where the canal bank was weak and where slides were liable to occur, a form as shown in figure 9, *b*, was adopted. In reducing the thickness from 6 to 4 inches a somewhat richer mixture was used and more precautions were taken to secure good drainage. The specifications for concrete called for a 1 : 2 : 4 Portland cement, sand, and gravel mixture, on which the contract price per cubic yard for concrete in place was \$6.80, while for a 1 : 2½ : 5 mixture, also used, \$6.45 was paid. On all straight portions of canal the concrete was laid in sections 20 feet wide. That placed on the bottom was first tamped into place and then carefully floated and smoothed. It was afterwards covered with sand kept moistened for a period of seven days by sprinkling. A 1 : 2 mortar of cement and sand was troweled over the surfaces of the slide slopes soon after the concrete had been tamped in and the forms removed. The slopes were then covered with burlap and kept moistened as described. The construction methods used on this canal are shown in Plate XI, figures 1, 2, and 3.

A tapering strip of wood, as shown in figure 3, *h*, forms the expansion and contraction joint between each section of concrete. The specifications called for the removal of these strips and the filling of the spaces with hot asphalt, but this was not done.

YAKIMA PROJECT, UNITED STATES RECLAMATION SERVICE, NORTH YAKIMA, WASH.

The Tieton main canal, located in the canyon division of this project, was provided for 10 miles of its length with concrete lining. Actual work commenced in 1907 and was finished in 1909. The steepness of the cross slopes, involving large excavation quantities per square foot of water area, and the lack of water-tightness in the material, made necessary an impervious canal and one that would withstand a high velocity. These requirements, together with a largely inaccessible locality having difficult working conditions, compelled the use of a minimum volume of lining, which it seemed advisable to make of molded concrete shapes cast in central yards. The cross section used for canals is shown in figure 10 and a portion of the constructed canal in figure 11.

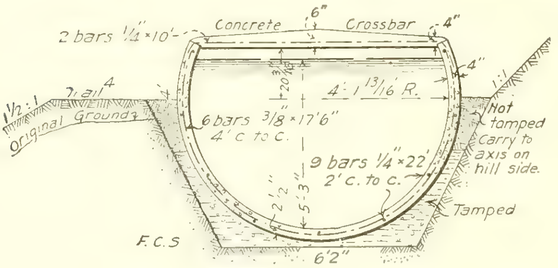


Fig. 10.—Cross section of open concrete-lined canal, Yakima project, U. S. Reclamation Service, North Yakima, Wash.

Curves of 57.6 feet radius were the maximum curvature used, and in some cases these were reversed with only a foot or two of tangent between. The canal was intended to have a carrying capacity of 300 second-feet.

The concrete aggregate was river gravel and sand and crushed gravel. The cost of manufacture of the lining per cubic yard was:

Cost of manufacture of lining for Tieton Canal.

Labor	$6.094
Material (cement and steel)	9.370
Plant charge	4.579
Engineering and inspection	.324
General	2.830
Total	23.197

The cost of placing and jointing a total of 49,494 lineal feet, including 23,295 shapes, raised the above cost to $32.05 per cubic yard, or $7.42 per lineal foot.

TURLOCK IRRIGATION DISTRICT, TURLOCK, CAL.

In 1910 this district made a hydraulic fill inclosing an old unsafe wooden flume on trestles across Peasley Gulch, and in the fall of that year, after the canal was emptied, the wooden flume box was removed and a concrete lining substituted. The lined section is 365 feet long, with a bottom width of 40 feet. The side walls, 4 inches thick and 9 feet high, are reinforced with No. 6 wire fabric (6 by 6 inches) and have a batter of $\frac{1}{5}$ to 1. Buttresses with the same batter are built at 8-foot intervals back of the lining and similarly reinforced. The floor, which is 6 inches thick and of the same construction as the sides, is concaved, being 1 foot lower at the middle than at the sides.

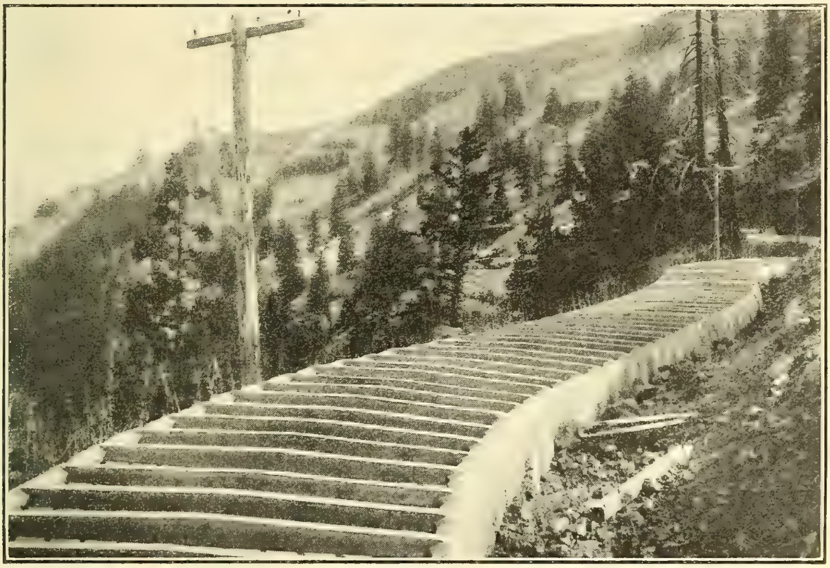


FIG. 11.—Concrete-lined canal, Yakima project, U. S. Reclamation Service, North Yakima, Wash.

Concrete floor ribs 12 inches deep and 8 inches wide are spaced equally with the buttresses and reinforced with two $\frac{1}{2}$-inch steel bars. The lining is made of 1:3:5 concrete placed behind wooden forms and cost $16 per cubic yard. It has no joints and no cracks of importance have developed.

MODESTO IRRIGATION DISTRICT, MODESTO, CAL.

Considerable concrete lining has been constructed to date in Modesto main canal, but all of it is for providing increased safety, and the small saving of seepage secured is merely incidental.

In the narrow canal sections near the headworks the velocities range from 5 to 8 feet per second. Where it has seemed necessary to provide considerable slab strength, the floor lining is from 4 to 6 inches thick. The linings for hydraulic fills recently completed are 6 inches thick and reinforced with No. 6 wire fabric 6 by 6 inches.

Linings of $2\frac{3}{8}$ to $2\frac{1}{2}$ inches thickness have been used on four stretches of lined canal having lengths of 250, 250, 575, and 1,000 feet, respectively. The bottom width is 44 feet and water depth of 5.5 for the first three and 34 feet and 7 feet, respectively, for the fourth. All slopes are 2 to 1. In preparation for the linings the canal sections were carefully graded and aligned by chalk line and straightedge. Fills were made a little high, with loose sand where possible, and after saturating with water were graded. Fills as high as 10 feet were graded and aligned within two or three days after the material was placed with a scraper, but they were made of clean sand thoroughly saturated with water. No settlement has been noticed. The lining was laid in cross strips 3 feet long longitudinally, and these were imperfectly bonded to permit cracking at the joints. The latter, being numerous, permitted only narrow cracks, which are unimportant. It is said that in part of this lining the water reaches a velocity as high as 20 feet per second at times and that no appreciable injury to the concrete has occurred after five or six years of use.

SOUTH SAN JOAQUIN IRRIGATION DISTRICT, MANTECA, CAL.

Concrete lining has been placed on 7 miles of the main canal, 3 miles of which is owned jointly with the Oakdale irrigation district. A typical lined channel has a bottom width of 11.36 feet, side slopes $\frac{1}{4}$ to 1, and is planned to carry a 9-foot depth of water and allow 2 feet additional for splash. This design, having a grade of 0.0775 per 100 feet, is intended to have a capacity of 850 second-feet. An excess grade for curves was computed from the following formula:

$$Hc = \frac{100\ v^3}{2gr^2},$$

where Hc is the excess grade in feet per 100 feet; v is the uniform velocity of water in feet per second; r is the radius of the curve in feet. The value of n for Kutter's formula was taken as 0.015. The lining thickness averages 4 inches for the bottom and 4 to 6 inches for the sides of the canal. A mixture of 1:3:6 concrete, placed behind forms and in alternate sections 12 to 16 feet long, was used without allowing expansion joints. In many places where the channel is in rock cut no back forms were used, and in such case the alignment is irregular and follows the contour of the side walls.

The cost of the concrete in the completed work was about \$14.50 per cubic yard.

BURBANK POWER & WATER CO., BURBANK, WASH.

This company concrete-lined about 4,000 feet of canal in 1910. The essential features of the design are shown in figure 12 and the construction is reported to be giving satisfactory results.

The contract price of the concrete in place was $12.50 per cubic yard, and the engineering 7 per cent additional. The cement cost

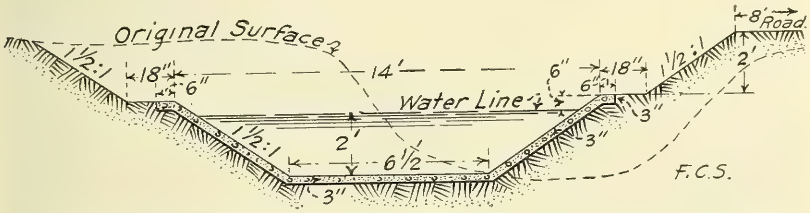


FIG. 12.—Cross section of concrete-lined canal, Burbank Power & Water Co., Burbank, Wash.

$2.75 per barrel at Burbank and $3.25 delivered at the work. Gravel and sand having within 5 per cent of the proportions used were found within a mile of the work and for which the contractor paid $1.75 per cubic yard delivered. The lining is made of a 1:2½:4½ mixture of concrete and is formed in cross strips 3 feet long.

MEDINA VALLEY IRRIGATION CO., SAN ANTONIO, TEX.

Concrete lining has been placed in 2,390 feet of the main supply canal having in this portion of its length a capacity of 850 second-feet. The canal, located on a sidehill slope of 3 to 1, is excavated in limestone having some pockets of rotten limestone and adobe. The ground surface is covered with a layer of broken stone and débris.

The work of excavation and placing of the lining was let to contract. In order to keep a low excavation cost the contractor blasted heavily and for this reason needed a large amount of rubble backfill. Figures 13 and 14 show the main features of construction and the dimensions of the section used. Joints are spaced 16 feet apart, and while cracks have appeared no harmful results are anticipated.

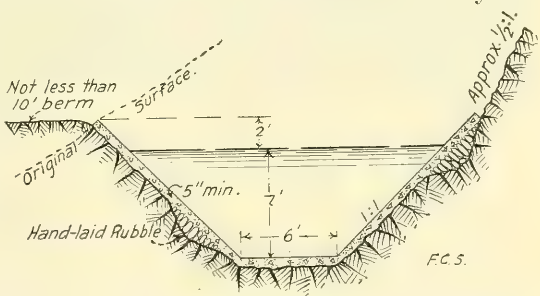


FIG. 13.—Cross section of concrete-lined canal, Medina Valley Irrigation Co., San Antonio, Tex.

Mexican labor, used on the work, cost $1.50 to $1.75 per day. The concrete was hand mixed, and except for the filling of local voids no plastering was done. The use of poor lumber for forms left an uneven concrete surface.

The contract prices were $0.90 per cubic yard for rock excavation, $6 per cubic yard for concrete in place, and $1.50 per cubic yard for dry laid rubble. The company paid for one-half the rubble needed for back filling the overbreakage. For the entire 2,390 feet of canal lined the costs per foot are:

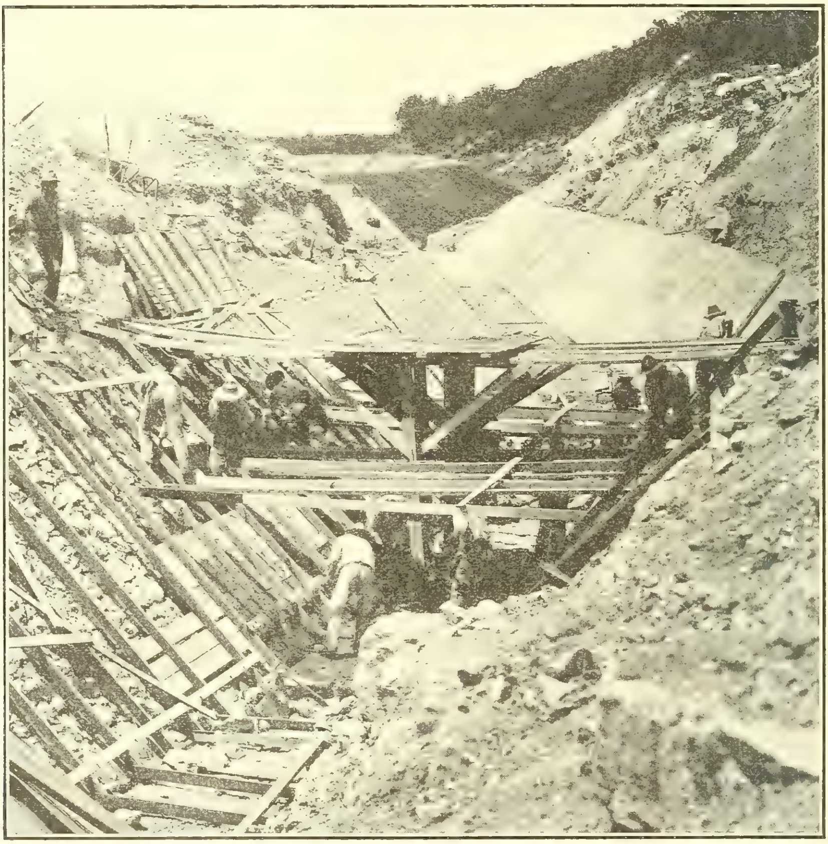
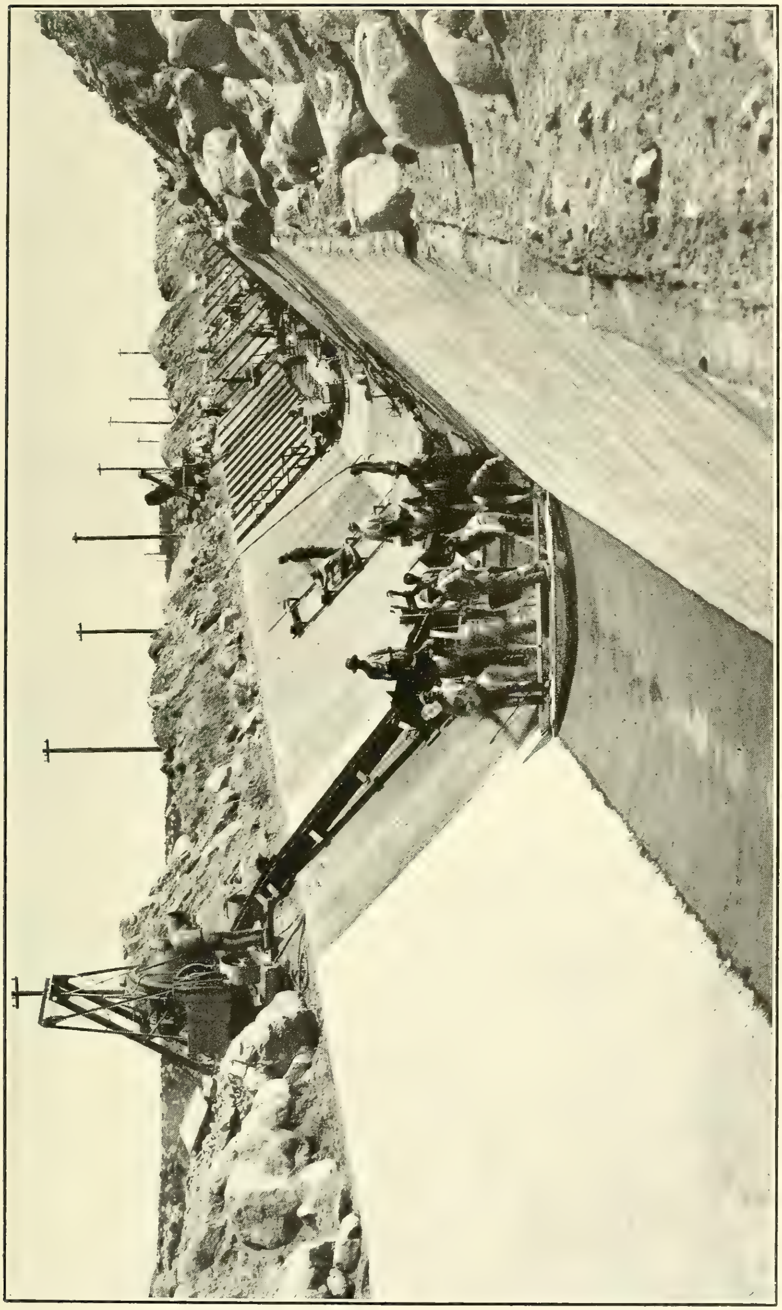


FIG. 14.—Construction methods used in placing concrete lining, Medina Valley Irrigation Co., San Antonio, Tex.

Contract prices and cost of lining Medina Canal.

	Approximate actual cost.	Cost to the company.
Excavation	$7.86	$10.56
Rubble	1.56	.86
Concrete	3.11	3.27
Cement	1.80	1.80
Total	14.33	16.49

Cement cost $2.40 per barrel delivered at a point on the railroad nearest the work. The cost of the concrete per square foot was 19 cents.



PORTION OF COMPLETED CONCRETE-LINED OPEN CHANNEL, LOS ANGELES AQUEDUCT. (NOTE THE CURVED BOTTOM.)

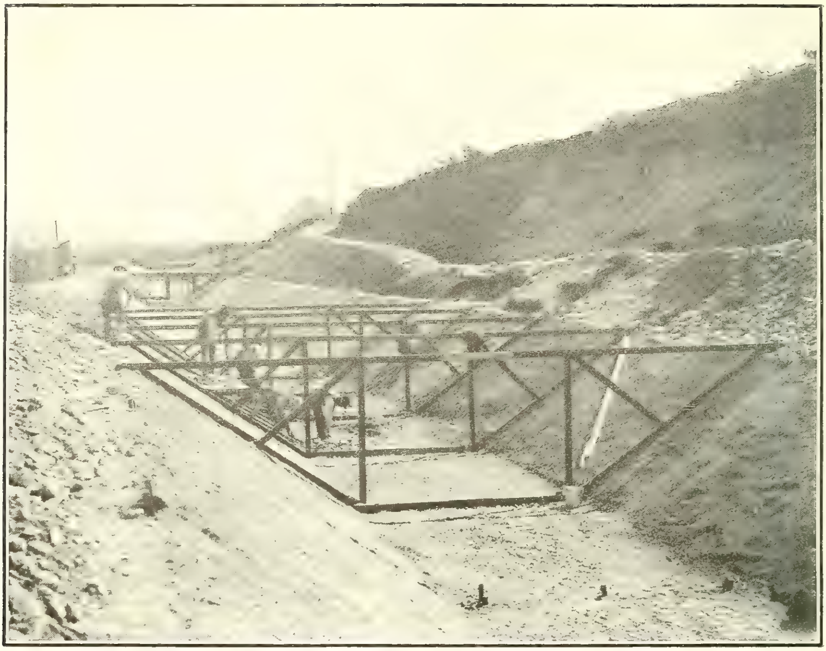


FIG. 1.—TEMPLATES USED IN PREPARING EARTH SECTION FOR CONCRETE LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

FIG. 2.—FORMS USED IN PLACING CONCRETE FOR LINING, RIDENBAUGH CANAL.

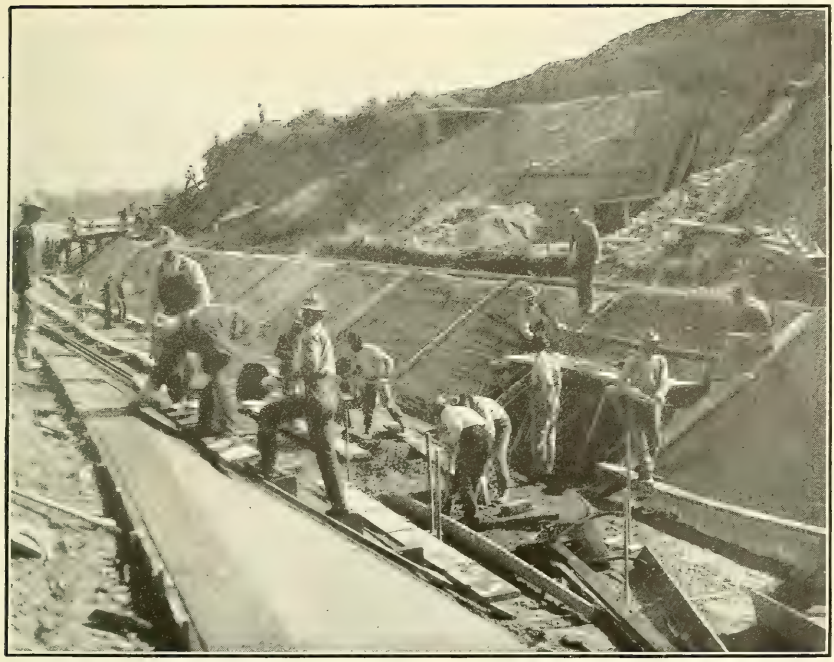


FIG. 1.—LAYING AND SURFACING CONCRETE ON SLOPES, RIDENBAUGH CANAL.

FIG. 2.—METHOD OF DELIVERING CONCRETE FOR SIDE LINING, RIDENBAUGH CANAL.

FIG. 1.—METHOD OF LAYING BOTTOM LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

FIG. 2.—A PORTION OF THE COMPLETED LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

THE LOS ANGELES AQUEDUCT, LOS ANGELES, CAL.

About 37 miles (196,402 feet) of canal forming part of this aqueduct is concrete lined. The excavation was made with a steam shovel, and some of the excavation was in very rocky ground. The slopes and bottom of the channel left rough by the steam shovel were brought to a fairly even surface by trimming off the high places, and the low portions were shoveled full of moist earth which was tamped to place. The guideboards set to allow a slab length of 12 feet were held to place by stakes driven into the earth.

In placing the concrete for lining, a platform was built half way up the slope, and in order to reach the upper half of the slope the concrete was handled a second time from this platform. Alternate slabs were first laid and these were brought to surface by the use of a straightedge supported on the guideboards. After this concrete had set and the forms were removed the intermediate slabs were concreted in and brought to a true surface, using the straightedge on the hardened slabs as guides. A ¼-inch plaster coat of 1:2 mixture was finally applied. The bottom lining was afterwards laid continuous and with a curved bottom as shown in figure 15. The work in various stages of construction is shown in Plate XII, figures 1 and 2, and Plates XIII and XIV.

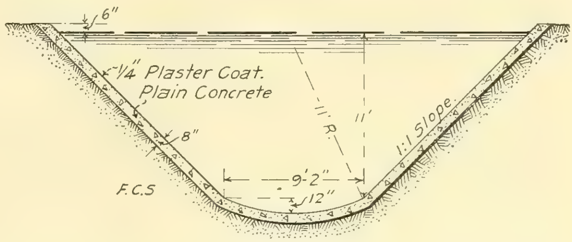


Fig. 15.—Cross section of concrete-lined channel, Los Angeles Aqueduct, Los Angeles, Cal.

This canal was designed to carry 923 second-feet of water at a mean velocity of 4.05 feet per second. The coefficient of friction n was taken at 0.014.

No reinforcement was used, and on most of the work the lining is made of a concrete mixture having 1 part cement to 6 parts sand and gravel, but in some portions a 1:5 mixture was used. A blended mixture of one-half tufa and one-half hydraulic cement was used for all the lining. The total cost of the concrete per cubic yard in place was about \$5, and the materials used in a cubic yard of concrete cost about as follows: Cement, \$2.60; sand and gravel, \$1; and mixing and placing, \$1.

RIDENBAUGH CANAL, BOISE, IDAHO.

The 2-mile portion of this canal which is concrete lined is along a gravelly sidehill that had formerly caused large seepage losses and expensive maintenance.

The lining has a $3\frac{1}{2}$-inch base overlaid with a $\frac{1}{2}$-inch top coating of cement mortar hand-troweled to a very smooth and even surface. The canal has a bottom width of 10 feet, $1\frac{1}{2}$ to 1 side slopes, and a vertical depth of $6\frac{1}{2}$ feet. At the top of the lining a 1-foot berm extends back into the bank. When carrying a 6-foot depth of water the canal has a capacity of 615 second-feet.

The lined portion of this canal offers an example of unusual care in construction to obtain a smooth interior. Its curves have been spiraled throughout. The lining is made up of 16-foot sections on tangents and 12-foot sections on curves. The exact shape of the finished section was secured by the use of a template having the same area as the cross section of the finished canal. The methods employed in construction and various details of the work are shown in Plates XV to XVII, inclusive. The concrete was laid continuously. Adjoining slabs were separated by one thickness of tar paper and connected by short lengths of $\frac{1}{2}$-inch steel rods used as dowel pins. The entire surface of the lining was plastered and smoothed with a steel trowel as soon as the concrete had set sufficiently to permit it, and which doubtless accounts for the absence of surface scaling.

No displacements due to pressure, settlement, or buckling are to be found in this lining. The only cracks which have appeared are those at the expansion joints. It has been noticed that in the summer these, found to be about 0.025 to 0.030 inch wide in the morning, are tightly closed by 1 or 2 o'clock in the afternoon.

A brief summary of data on various canal linings is given in Table IV for the purpose of supplementing that contained in the text

TABLE IV.—*Summary of data on various canal linings.*

Name of canal or system and location.	Size of canal. Bottom width.	Size of canal. Depth.	Size of canal. Side slopes.	Length lined.	Thickness of lining.	Mixture used.	Cost of cement per barrel delivered.	Cost of sand and gravel per cubic yard.	Wages per day.	Total cost per square foot of lining.	Remarks.
	Feet.	*Feet.*		*Miles.*	*Inches.*						
Tucson Farms Co., Arizona	2–4¾	3	1–1	2½	3	1:4:4 and 1½:4:4	$3.24		$2.00		Reinforced concrete, $14.03 per cu. yd.
Belgo-Canadian Fruitlands Co., British Columbia.	¾–3½	2¾	½–1	4½	2½–3	1:2:4	3.75		2.75 $3.00–4.00	$0.118 .130 .142	See p. 70; data are for laterals only.
Los Angeles Aqueduct, California				37		1:6 and 1:5					Concrete, about $5 per cu. yd. in place.
Modesto Irrigation District, California.	34–44	7–5	2–1	0.43	2⅜–2½						Lining in some of the fills reinforced with No. 6 wire fabric.
Patterson Land & Water Co., California.	4½–7		1½–1		3¼	1:6 or 6½					3-in. concrete plus a ¼-in. 1:2 coat of mortar.
South San Joaquin Irrigation District, California.	11.36	11	1–1	7	bottom, 4 sides, 4–6	1:3:6					Concrete, $14.50 per cu. yd. in place.
Turlock Irrigation District, California.	40		¼–1		walls, 4 floor, 6	1:3:5					Length, 365 ft.; reinforced with No. 6 wire mesh and 2½-in. bars; concrete in place, $16 per cu. yd.
New York Canal, U. S. Reclamation Service, Idaho.	40	8	1½–1	6½	4	1:3:6			2.50	.14	Surface painted with 1:2 mortar; cost of lining per lin. ft., $9.64.
North Side Twin Falls Land & Water Co., Idaho.	40–60		1¾–1 and vertical	1.59	earth, 4 rock, 6–8	1:3:6 and 1:6					Concrete cost $16.50 per cu. yd.
Payette-Boise Project, Idaho	40	8+	1½–1	1.82	4	1:3:6			*a* 5.00		Surface 1:2 mortar; laid in cold weather; some heating required; labor for mixing and placing concrete, $2.20 per cu. yd.; entire cost of lining, $9.64 per lin. ft.
Ridenbaugh Canal, Idaho	10	6½	1½–1	2	3½						In addition, a ½-in. coating of cement mortar.
Truckee-Carson Project, No. 1, Nevada.	20		½–1	.95	6	1:3:5	2.55			.166	Does not include riprap backing (Eng. News, Oct. 18, 1906).
Truckee-Carson Project, No. 2, Nevada.	8.9		½–1	1.4	6	1:3:5	2.55			.16	
Central Oregon Irrigation Co., Oregon.						1:4:5					
Umatilla Project, Canal M, Oregon.	4	4	1¼–1	2.35	1½	mortar 1:4	2.40	$0.85	2.40	.062	A 4 by 3 in. curb at the top.
Umatilla Project, Canal L, Oregon.	2	2½	1¼–1	.6	1½	mortar 1:4	2.00	2.75	2.40	.054	
Umatilla Project, Canal T, Oregon.	3	3	1¼–1	1.0	1¾	mortar 1:4	2.25	1.20	2.40	.069	Do.
Umatilla Project, Canal A, Oregon.	15	5	1¼–1	.6	2	mortar 1:4	2.30	1.25	2.40	.071	Side lined only.
Umatilla Project, other canals, Oregon.	1–4	1½–3½	1¼–1	1.7	1½	mortar 1:4	2.85	1.25	2.40	.085	Scattered portions only.

a For 8 hours.

TABLE IV.—*Summary of data on various canal linings*—Continued.

Name of canal or system and location.	Size of canal.			Length lined.	Thickness of lining.	Mixture used.	Cost of cement per barrel delivered.	Cost of sand and gravel per cubic yard.	Wages per day.	Total cost per square foot of lining.	Remarks.
	Bottom width.	Depth.	Side slopes.								
	Feet.	*Feet.*		*Miles.*	*Inches.*						
Medina Valley Irrigation Co., Texas.	....	....	3–1	.45	....	....	....	....	$1.50–1.75	$0 21	Cost includes back fill: see p. 80.
Davis & Weber Counties Canal Co., Utah.	....	....	....	9.5	mostly 4 some 6	1:2:4 and 1:2½:5	....	....	....	....	6-in. drain tiling used below a portion of the lining.
Burbank Power & Water Co., Washington.	....	....	....	.76	....	1:2½:4½	$3.25	1.75	2.25	....	Cost of concrete in place, $12.50 per cu. yd. + 7 per cent for engineering.
Hanford Irrigation Co., Washington.	8	....	1½–1	5.6	¾–1½	....	4.52	2.27	....	.051	Water per cu. yd. concrete, $0.39; not first-class construction.
Lower Yakima Irrigation Co., Washington.	11.5	....	1½–1	5	1¾	1:3:4	3.10	....	[b] 2.50	.065	Contract for mixing and laying, $0.025 per sq. ft.
Northern Pacific Irrigation Co., Washington.	3–3.5	2.2–1.5	½–1	4.3	2	1:3:4	3.00	1.75	2.50	.122	Work done in cold weather; heating required.
Yakima Project, U. S. Reclamation Service, Washington.	....	....	....	....	....	....	....	....	....	....	49,494 lin. ft. of canal lined, at $32.05 per cu. yd. of concrete in place, or $7.42 per lin. ft. of lining. Work in rough country.

[a] For 10 hours.

CARE TO BE EXERCISED IN OPERATION.

The durability of concrete lining for canals depends not only on good construction but on the care given it as well. Sudden changes of temperature, such as turning out cold water and exposing a lined channel to a hot sun, damage from roots of trees, damage from stock and storm water, the formation of ice, etc., may be very injurious and destructive to good construction unless proper precautions are taken.

The flow in the Davis and Weber Counties Canal in Utah some years ago had been turned out in the early spring when the water was cold. The effect of a hot sun on the concrete lining caused it to expand and buckle in a few places. The lining had been amply provided with expansion joints, but the wooden cleats used during construction had not been removed. No harm would have resulted if the strips had been removed and the joints filled with asphalt. This instance is mentioned to show how injury may occur through carelessness in construction and operation. In such connection can be seen the benefits arising from the use of a somewhat lean mortar for the finishing coat and thus avoid as much as possible the shearing effect between the base of the lining and the surface coat due to the inequality of their coefficients of expansion.

The growth of trees along or near the banks of a canal may injure a concrete lining by the displacement or breaking of individual slabs. The possibility of such injury may be guarded against during construction by entirely removing or cutting back and deadening the tree growth.

Fencing the right of way is the only remedy against damages caused by stock.

Any storm water which is likely to be discharged into the canal should be bypassed. A cloudburst or heavy rainstorm may so raise the height of water in the canal as to endanger its safety, and the flow from even small volumes of storm water entering a canal is usually destructive to the upper part of the lining by washing away the earth backing.

If it becomes necessary to operate a concrete-lined canal in freezing weather, every precaution should be taken to avoid injury that may arise through the formation of ice. One of the principal rules to be observed is to increase, rather than diminish, the flow prior to the beginning of the ice-forming period. The writer has discussed the operation of canals in winter elsewhere.[1]

The formation of ice in a concrete-lined canal is not necessarily injurious. In such instance the canal should be operated to obtain a condition as mentioned in the preceding paragraph and referred to

[1] U. S. Geol. Survey Water-Supply and Irrig. Paper 43 (1901).

in the discussion cited. The greater the surface width of the water in the channel at the time the ice is formed the greater will be the tendency for the ice sheet to bulge upward and thus relieve the side thrust. Again, the flatter the side slopes of the channel the greater will be the upward component of force parallel to the lining surface and accordingly the less will be the thrust normal to its surface. Of course there are many reasons for limiting the flatness of the side slopes, but in the design of concrete-lined canals for use in localities subject to low temperatures, and particularly where winter operation is necessary, the benefits resulting from flattened side slopes should not be overlooked.

ACKNOWLEDGMENT.

The grateful acknowledgment of the writer is hereby tendered to the engineers and managers of irrigation enterprises and to the field members of this division who have assisted in collecting reliable information pertaining to the subject treated. He is especially indebted to S. T. Harding and Justin T. Kingdon for able assistance rendered in compiling the data and computing the tables contained in this report.

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THE MYCOGONE DISEASE OF MUSHROOMS AND ITS CONTROL.

By F. J. Veihmeyer, *Formerly Scientific Assistant in the Office of Pathological Collections and Inspection Work.*

INTRODUCTION.

The industry of mushroom growing in this country has been steadily increasing until to-day large establishments for the cultivation of mushrooms are found in the vicinity of nearly all of the large cities. In the eastern part of Pennsylvania there are many extensive mushroom plants which supply the eastern markets. In one section there are more than 250 establishments whose collective product exceeds 1,000,000 pounds of mushrooms annually, while many of the growers individually send to market over 100,000 pounds a year. The substantial manner in which the modern mushroom houses are constructed and the extent and operation of the individual plants represent investments of considerable magnitude; consequently, the failure of a crop in even one mushroom house means a serious financial loss to the grower. Because the knowledge and conditions necessary for the successful cultivation of mushrooms are peculiar and unique, and while it is recognized that various factors—such as an unsuitable degree of humidity, imperfect ventilation, improper preparation of the beds, the presence of insects, and other unfavorable conditions—may be the cause of the loss of a crop or a large percentage of it, the growers have only recently been led to appreciate that a fungous disease is responsible for extensive losses.

PREVALENCE OF THE DISEASE IN MUSHROOM BEDS.

Many instances of total failures of mushroom houses are recorded. For example, one grower reports the complete failure of four houses and about two-thirds of another house. Houses that should have

Note.—This bulletin describes a disease of mushrooms which causes great losses to growers and gives methods of control. Of interest to mushroom growers generally.

produced more than 30,000 pounds yielded less than 1,000 pounds of mushrooms, owing to the ravages of this fungous disease. An establishment containing over 50,000 square feet of mushroom beds was abandoned on account of the heavy losses sustained.

While the disease is prevalent in most localities where mushrooms are cultivated on a large scale, there are mushroom-raising plants in these infected districts where the disease has never made its appearance. There is, however, evidence of a local distribution of the disease, and unless proper measures to control the fungus are taken it will be only a question of time before all mushroom houses are infected.

Costantin and Dufour (1892*c*)[1] state that under the ordinary conditions of cultivation in a great number of the caves or underground quarries in which mushrooms are cultivated abroad, the proportion of diseased to normal mushrooms is about 1 to 10. In less frequent cases this proportion rises to 1 to 4. Costantin and Dufour and Répin (1897) report the losses to the Parisian mushroom growers caused by this disease to be about $200,000 yearly. This loss is based on a daily estimated production of about 56,000 pounds, at 66 cents per pound, the yearly production having a value of approximately $2,600,000 and losses due to the disease being estimated at probably one-tenth of the production. As nearly as can be ascertained these figures apply to the year 1892.

OCCURRENCE OF THE DISEASE IN AMERICA.

The occurrence of the fungous disease of cultivated mushrooms in America was first called to the attention of the Department of Agriculture in 1909, when specimens of diseased mushrooms were sent to the department with requests for a diagnosis of the trouble. A microscopic examination revealed the presence of a fungus, a species of Mycogone, similar to, if not identical with, the species causing the European disease of mushrooms known as la môle.

HISTORICAL REVIEW OF THE MYCOGONE DISEASE.

OCCURRENCE IN EUROPE.

The Mycogone disease of cultivated mushrooms has been known in England, France, and Germany for many years. In France it is reported as having been recognized "for at least three generations of mushroom growers," and it is believed that it was known at a much earlier date. Probably the first reference to the disease in scientific literature was that of Magnus, who described it in 1888 as being the most serious enemy of mushroom growing around Berlin.

[1] All references to literature are indicated in the text by the name of the author and the year of publication. For full citations, see the list at the end of this bulletin.

IDENTITY OF THE FUNGUS.

The common identity of the fungi studied by different investigators in relation to the disease of mushrooms has not been established, but it is interesting to note that in each study one of the three concerned in the life history of the fungus causing the mushroom disease, e. g., Mycogone, Verticillium, or Hypomyces, is the subject of investigation. Owing to the similarity of the fungus causing the disease to certain stages of diseases of wild species of mushrooms, Magnus called the fungus *Hypomyces perniciosus*. No technical description was given by this author and the fungus was only a hypothetical stage of Hypomyces.

Cooke (1889) in England identified the fungus which was causing considerable loss to mushroom growers as "a species of Mycogone not unlike *Mycogone rosea* in many of its features, but referable to *Mycogone alba*," notwithstanding the fact that he described the larger cells of the Mycogone spores as becoming amber colored.

In Vienna, Austria, Stapf (1889) described a disease of cultivated mushrooms, which was attributed to *Verticillium agaricinum* Corda, a conidial stage of *Hypomyces ochraceus* Pers. Stapf found several spores of Mycogone, but could not connect them with Verticillium.

Prillieux (1892) described a disease of mushrooms and identified it as *Mycogone rosea*, which by analogy he considered a conidial stage of *Hypomyces linkii* Tulasne, although the perfect stage of the fungus had never been observed.

In the same year Costantin and Dufour (1892*a*) published a note on the disease then known as "la molle." They described the macroscopic and microscopic characters of the disease and stated that the fungus is very similar to *Mycogone cervina*, though it differs in habitat, or host plant. Two types of modification of the mushroom caused by the fungus are described. In the first type the cap, stipe, and gills are well defined, though the presence of the disease is indicated by a stipe swollen at the base, swelling of the gills, and distortion of the cap. The second type of the disease is manifested by an early arresting of the development of the mushroom, the cap is rudimentary or entirely lacking, and the stipe, or stem, is swollen to such a size that the affected mushroom has the appearance of a puffball. On the diseased mushrooms of the first type Mycogone and Verticillium spores were found. The Verticillium spores were long, cylindrical-oblong, and sometimes two celled. The relationship of these two forms, Mycogone and Verticillium, was established by finding the two kinds of spores growing on the same mycelium. The second or puffball-like type of diseased mushrooms has only a Verticillium with small unicellular spores, microscopically quite different from the Verticillium of the first type.

It was at first thought that there were two different diseases, but when a sufficient number of specimens were studied all transitions between the two forms of Verticillium were found and it was established that it was one disease with two very dissimilar forms of fruiting bodies.

Costantin explained that, together with Dufour, he had previously stated that the fungus was similar to *Mycogone cervina*, but that they had not identified it with that species. The fungus also did not agree with the description of *Mycogone rosea*.

Costantin and Dufour (1892*c* and 1893*a*) give the most exhaustive study of this disease of cultivated mushrooms. They discuss the two characteristic types of infection, as described in their previous article, designating them as the common form and the scleroderma or puffball-like form. The discussion of the fungus immediately following embodies the observations made by these authors. A microscopic examination of the common form, as previously described, revealed the presence of a Verticillium having large spores variable in size and form. The large spores are two celled, 16 to 20 by 3.5 μ, while the small spores are more numerous and one celled, 8 by 3 μ. This Verticillium is usually found on the gills in an early stage of the disease. At a later stage of the disease the mushroom is covered with a thick white coating consisting of long irregularly and verticillately branched hyphæ, upon which are borne bicellular "chlamydospores" of a Mycogone. In rare cases these large Mycogone spores are three celled and much longer than the usual 2-celled spores. At first these two cells are smooth, hyaline, or colorless, and almost equal in size; later the terminal cell becomes swollen, amber colored, and covered with warts. It is spherical in shape and measures about 16 to 20 μ. The lower or basal cell is smaller, smooth, colorless, and 14 to 16 μ in size.

In specimens of the puffball-like type of infection the color is at first a dirty white, becoming pearl gray or pale rose gray as the disease advances. In this latter stage the deformed mushroom is covered with a light velvety tomentum or hairlike coating formed of little tufts or filaments much more branched and scattered and thinner, but still of the form of Verticillium. The spores are unicellular, more numerous than the form just described, and much smaller, being 4 by 2 μ in size.

Magnus (1906), Cooke (1889), and Prillieux (1892) probably observed the disease in the common form, i. e., the Verticillium with large spores and the Mycogone spores, while Stapf (1889), who reported only a Verticillium stage, examined the disease in the puffball-like stage, where only the Verticillium with small spores was present.

As previously suggested by Costantin and Dufour, it might be supposed that these two forms of Verticillium belonged to two distinct diseases. A specimen was found infected in the puffball-like manner which had a rose-gray velvety covering and at the same time a whitish woolly coating, on the lower part the Verticillium with small spores, and on the upper part Mycogone and the Verticillium with large spores. There was a gradual transition from the Mycogone and large-spored Verticillium to the small-spored Verticillium. The conclusion is then drawn that there is one disease with two forms of Verticillium. This is an interesting fact, since Costantin and Dufour by sowing the large-spored Verticillium in suitable media produced Mycogone spores. The cultures were at first drab in the center and white at the margin, finally becoming a color intermediate between light leather and umber. It was impossible to cultivate the large-spored Verticillium alone, as this form was always accompanied by the production of Mycogone spores.

When cultures were made from the small-spored Verticillium of puffball-like infected mushrooms, they remained permanently white and only the Verticillium with small spores was produced. Never could the small-spored Verticillium be made to take the characters of the large-spored Verticillium.

It is concluded that this parasite of the cultivated mushrooms differs from *Mycogone rosea* and *Mycogone cervina* in habitat, size, and color of the "chlamydospores," but that it is the species named by Magnus (1906) *Hypomyces perniciosus*, although his description was insufficient and he regarded the "chlamydospores" as being hyaline, whereas this is only the case in immature spores, for they rapidly become amber colored. The authors designate the species as *Mycogone perniciosa* Magnus.

Evidently Prillieux (1892), who believed the species to be *Mycogone rosea*, later agreed with Costantin and Dufour in considering it *Mycogone perniciosa*, for the sketch he presented before the Botanical Society of France has been reproduced and designated as *Mycogone perniciosa* (Prillieux, 1897).

Delacroix (1900) described the disease "la môle" as the most important of the diseases of cultivated mushrooms, and ascribed it to the fungus *Mycogone perniciosa* Magnus.

Magnus (1906) discussed the work of preceding investigators and concluded that the *Verticillium agaricinum* (Lk.) Cda. given by Stapf (1889) as causing a serious disease of cultivated mushrooms at Vienna is rather *Mycogone rosea* Lk. than *Mycogone perniciosa* Magnus as given by Costantin and Dufour. However, the question of specific identification is one which Magnus states requires further study.

The fungus causing the disease in American houses is probably the one described by Costantin and Dufour (1892*c*) and called *Mycogone perniciosa* Magnus. Costantin (1893*a*) gives the morphological differences between *Mycogone rosea* and *Mycogone perniciosa*, and, although there has been no opportunity to compare our fungus with the European species, it is thought that the two species are identical, as they agree in both macroscopical and microscopical characters.

INVESTIGATIONS OF THE MUSHROOM DISEASE IN AMERICA.

TYPES OF THE DISEASE.

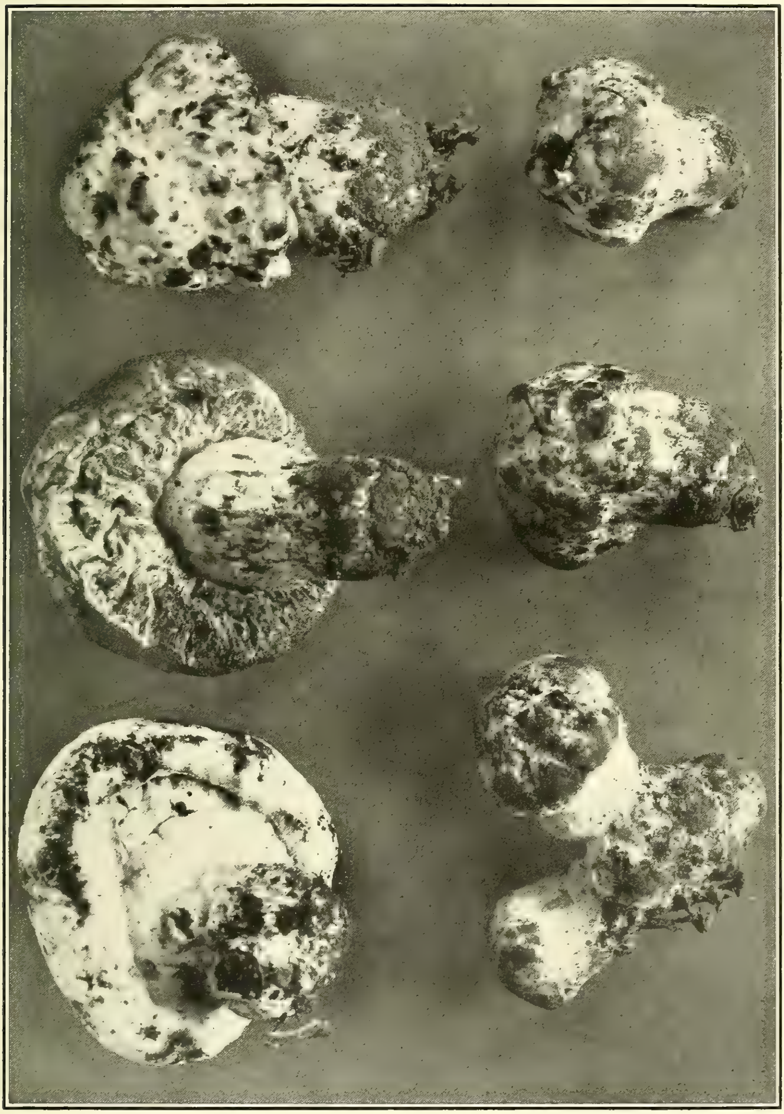
During the course of the present investigation, specimens of the two types or forms of infection as described by the French investigators were collected in diseased mushroom houses in this country. In many cases it was difficult to determine to which type the diseased individuals belonged, as there are gradations between the two forms. Often cap, stipe, and gills are clearly defined, the presence of the malady being indicated by small tubercles on the cap and a fluffy white growth on the gills, a form of the disease known in France (Costantin and Dufour, 1892*c*, p. 471) as "chancre."

In this country the common form of the disease is similar to that in France. The mushrooms are covered with a white, velvety coating, which consists of interwoven hyphæ. This growth prevents the normal development of the individual gills, which become more or less coalescent, a condition shown in Plate I. The progress of the disease is also frequently accompanied by arrested development and by the distortion of the cap and stipe, as well as by the general darkening and decay of the tissue. These characters are illustrated in Plates II and III.

In cases of infection termed by the French the "scleroderma" form, the stipe is bulbous and the cap rudimentary or entirely lacking. In this form the gills are completely aborted, and the diseased mushroom is covered with a coating of interwoven hyphæ similar to that of the common form. It has been observed that in this form of the disease the plants are much softer than in the other form and that they decay more rapidly. Monstrous soft masses with thick white coatings of the fungus are often observed in houses in which the disease is abundant. These infected plants have very little resemblance to mushrooms, and they decay rapidly, forming a putrid mass which emits a disagreeable, almost acrid odor. Figure 1 illustrates one of these masses. Clumps greatly exceeding this in size are often found.

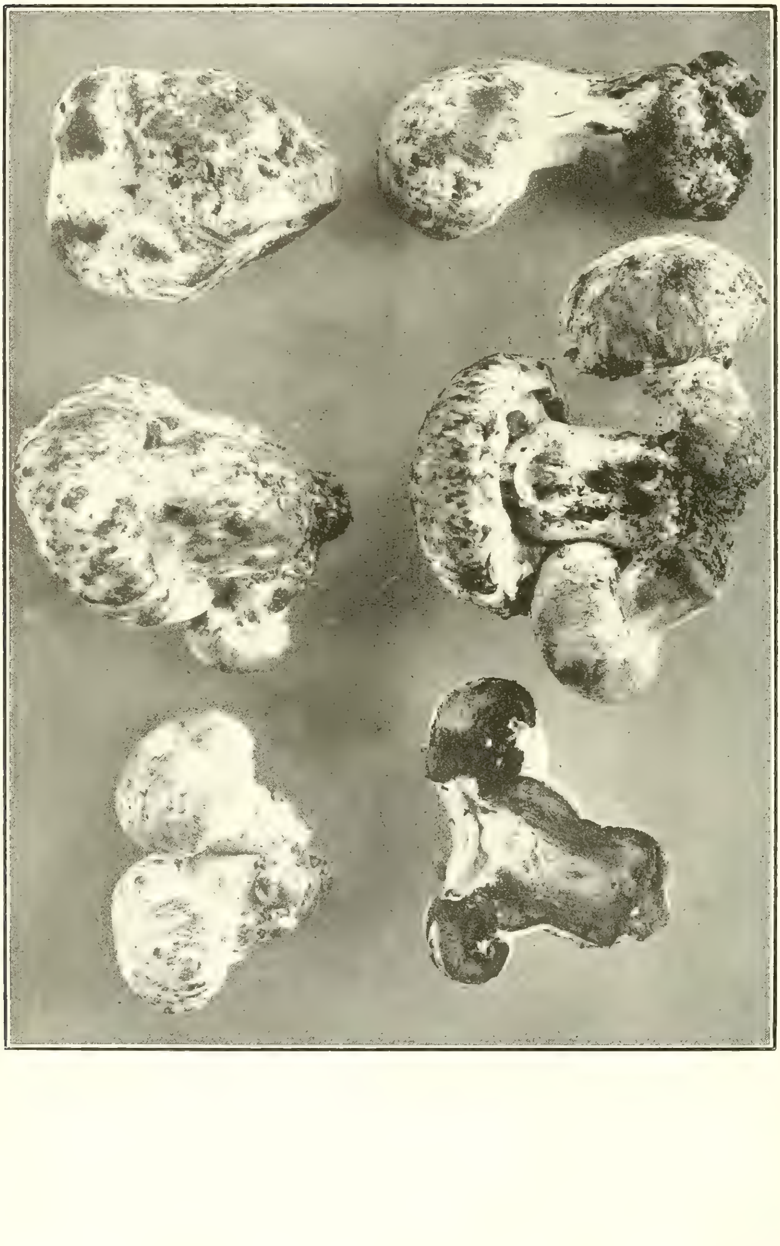
MICROSCOPIC CHARACTERS OF THE FUNGUS.

The small-spored Verticillium described by Costantin and Dufour (1892*c*) has not been observed in the specimens examined from American houses, but it has been possible to grow the Mycogone in



THE COMMON OR USUAL TYPE OF MALFORMATION OF MUSHROOMS, ILLUSTRATING THE DESTRUCTIVE EFFECT OF THE MYCOGONE DISEASE.

These specimens are covered with the cottony growth of the parasite, two of them showing the coalescence of the gills.



DISEASED MUSHROOMS, ILLUSTRATING MALFORMATIONS DUE TO THE MYCOGONE DISEASE.

The cross section shows the darkening or decay of the tissue from the same cause.

EXAMPLES OF THE PUFFBALL-LIKE TYPE OF DISEASED MUSHROOMS AND TWO NORMAL SPECIMENS.

The characteristic distortion of mushrooms of this type is clearly shown in comparison with the healthy specimens.

cultures from inoculations made indiscriminately from the common and sclerodermalike forms. Further investigation, however, may demonstrate the occurrence of this small conidial form.

Figure 2 illustrates the Mycogone stage of the disease. During the course of the present investigation many hundreds of cultures were made, both from infected material and by transfers from pure cultures of the fungus. With few exceptions, spores of Verticillium developed first and later were followed by Mycogone. The spores of Verticillium are hyaline, oblong cylindrical, and borne on tapering branches. They are generally one celled, but occasionally larger, 2-celled spores are developed. They are variable in size, the average measurement being 20 by 3.5 μ for the larger 2-celled spores. The cell wall is uniformly thin. Often, as noted by Costantin and Dufour

FIG. 1.—Irregular mass of a diseased mushroom growing among normal mushrooms.

(1892*c*) and Prillieux (1897), these Verticillium spores were borne on the same hyphæ as the Mycogone spores. The Mycogone spores were usually produced at the bases of the hyphæ strands and the Verticillium spores at the apexes.

Figure 2 is an illustration of the Mycogone spores and the manner in which they are produced on the mycelium. They are two celled, the upper cell spherical and rough or covered with warts. At first, both cells are hyaline or colorless; later, the upper cell becomes light brown, the lower cell usually remaining hyaline, but in rare cases becoming faintly tinged with brown, averaging in size from 20 to 30 μ. The cell walls are thick, while the spores of the Verticillium possess very thin walls.

THE DISEASE IN MUSHROOM BEDS.

The study of the mushroom disease in America has proved the fungus to be exceedingly variable as regards the time of its appearance. In some instances evidences of Mycogone were observed when the mushrooms were just beginning to appear; again, the crop was well developed before being attacked by the parasite. The experience of the French growers also proves that the time of the appearance of the disease is subject to great variation, but that ordinarily it reaches its height about the middle of the productive period of the beds.

The occurrence of diseased mushrooms in an infected house is very sporadic. Sometimes isolated diseased specimens will appear among normal mushrooms, while again perfectly healthy mushrooms will be observed growing in a badly diseased bed. An example of a badly diseased specimen growing among normal mushrooms is illustrated by figure 1.

FIG. 2.—Mycogone spores, showing the thick-walled and warty cells. Magnified 425 diameters. From a photomicrograph by Dr. Albert Mann.

PROPAGATION AND DISSEMINATION OF THE DISEASE.

The manner in which the parasite is propagated in the beds is only partially known, but from the experience of foreign growers and the studies of the writer there can be little doubt that the disease is distributed by the spawn and that the fungus grows up with the mycelium of the mushroom, which it finally attacks and destroys.

A thorough investigation of one of the American mushroom spawn-manufacturing plants in which the so-called "tissue method" of spawn making is practiced leads to the conclusion that there is little chance of the disease being carried by the spawn where proper precautions are taken to prevent infection. To prevent infection of the spawn entails great care on the part of the manufacturer. He must be absolutely sure that his cultures are made under sterile conditions and that the bricks are kept from any chance of contamination by spores of the parasite. Investigation and inquiry among most of the large growers in this country have disclosed the fact that the disease is as prevalent in the beds of growers who use imported spawn entirely as among those who use domestic spawn. Instances of the use of both foreign and American manufactured spawn by growers in localities where the disease was present have been noted in which there was no trace of the disease. It is the general opinion among American growers that the disease was introduced by imported spawn.

In the course of the present investigations it has been possible to propagate the parasite in the laboratory on pieces of blank spawn bricks[1] in sterilized bottles. The mycelium of the fungus spreads over the pieces of brick, eventually fruiting and producing spores of Verticillium and Mycogone. These experiments prove that under proper conditions the parasite will grow on the spawn bricks. The growth of the fungus appeared to be superficial, and it could not be ascertained whether or not the mycelium penetrated the bricks. No reliable method has yet been evolved to determine the presence or absence of the mycelium of Mycogone in spawn bricks. The observation of the writer has been that there are no marked differences between spawn in an infected bed and that in healthy beds.

Although our knowledge is incomplete as to the exact way in which the parasite spreads through the beds, because of insufficient experiments on this phase of the subject, it seems probable from the limited data that the parasite does grow through the manure of the mushroom beds and attacks the developing mushrooms, producing spores by means of which the disease may be carried to other beds. In addition to this method of reinfection, the question suggests itself as to whether the fungus may not persist for long periods in the lumber used in the construction of houses or beds. In order to determine this point many cultures were made from the wood secured from diseased houses, but at the present time no definite conclusions can be drawn.

LONGEVITY OF THE FUNGUS.

In order to obtain data which would be of assistance in devising a method for the control of the mushroom disease, two distinct lines of investigation on the subject of the longevity of the fungus were inaugurated. Laboratory and field experiments were continued during a period of over three years. While the experiments were not sufficiently exhaustive to be conclusive, they are significant and interesting.

Laboratory experiments.—Many different sets of cultures were made on corn meal in 100-cubic-centimeter flasks. These were opened, examined, and transferred at certain periods in order to ascertain

[1] Blank spawn bricks are bricks in which the mushroom mycelium has not been "run," or grown.

their power of germination. Several hundred cultures were made during this series of experiments, and no growth was produced from cultures after a period of 18 months. It should be stated, however, that the cultures were kept in a dry place and were consequently thoroughly dried out at the termination of 18 months. That the organism retains its vitality for such a period and on an artificial medium demonstrates its dangerous nature. The probability is strong that in the mushroom house, under more favorable conditions of humidity and temperature, it would retain its power of germination much longer.

Field observations.—The writer's opportunity to study the vitality of Mycogone in the beds of different mushroom houses has covered a period of about three years. One case for observation was that of a new house in which earth was mixed with manure from a badly infected house, which manure had been exposed to the weather for five years. This house produced a splendid crop of mushrooms, which indicates that the fungus exposed to the weather had not retained its vitality at the close of this period. A case in which the fungus persisted for three years is cited by Costantin. Two caves were held under observation; one was new, while the second had been used for mushroom cultivation for over 30 years, although the culture had not been continuous. This second cave was idle for three years before being employed for this experiment. The yield of the new cave exceeded that of the second, and the presence of the disease in the first was negligible, while in the second it was considerable. The conditions and attention in the two caves were practically the same, and, while the report does not mention what precautions were observed to prevent infection of the new beds, the result would indicate that the spores in the abandoned cave had retained their vitality for at least three years.

CULTURAL STUDIES TO DETERMINE A MEANS OF CONTROL.

Many hundreds of cultures of Mycogone were made during the course of the present investigation, for the purpose of studying the development and habit of the fungus and observing the direct effect of fungicides and disinfectants upon the organism. It was found that the fungus could be cultivated upon numerous different media, but as corn meal in flasks and corn-meal agar proved very congenial media they were employed in most of the experiments. The fungus grew rapidly, producing vigorous cultures, and practically no difficulty was experienced from contaminations even when fresh cultures were made directly from diseased mushrooms on which spores of various fungi were doubtless present. Figure 3 shows a photograph of one of the cultures, all of which exhibited a similar vigorous growth. In the early stages the cultures of the fungus were white, soon becoming drab in the center and finally light brown. As the method of growth is centrifugal and the marginal growth of the culture is the youngest, it is the last to become brown. The most important physical factor concerned in the growth of the fungus in culture proved to be humidity. While ordinarily low temperatures are not conducive to the growth of fungi, in the present instance it was found that a moist atmosphere was more important to the growth of the cultures than a high temperature. This observation was made from the study of numerous cultures in flasks and tubes and on various media subjected to different degrees of humidity maintained at various temperatures. Cultures grew at a temperature as low as 2° C. (35.6° F.) when considerable moisture was present, while cultures at a temperature of 35° C. (95° F.) in a dry atmosphere failed to produce any growth. This peculiarity of the fungus is an important factor in the method of fumigation.

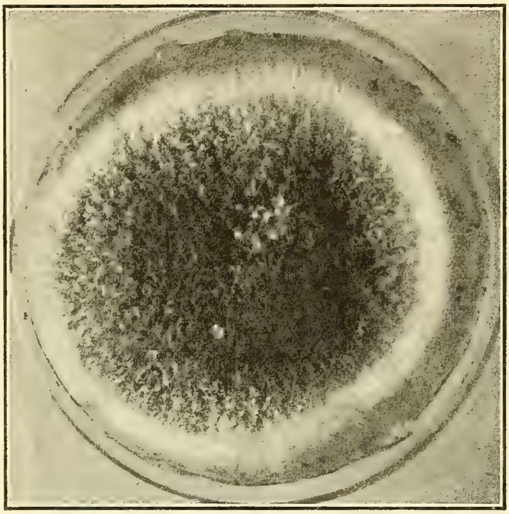


FIG. 3.—Petri-dish culture of Mycogone on corn meal, 211½ hours after inoculation made from an infected mushroom.

TREATMENT WITH FORMALDEHYDE GAS.

In view of the important rôle of formaldehyde as a disinfectant and fungicide and the success obtained from its use in inhibiting the growth of certain parasitic fungi (Patterson, Charles, and Veihmeyer, 1910), a series of laboratory experiments was performed to determine the effect of formaldehyde upon the Mycogone disease of cultivated mushrooms.

The apparatus used in these experiments is fully described and illustrated in Bulletin No. 171 of the Bureau of Plant Industry. It consists of a large air-tight box provided with a glass door and a set of drawers, whereby cultures can be withdrawn from the box at any time during the process of fumigation with a minimum loss of the formaldehyde gas.

CHEMICALS EMPLOYED.

The formalin employed in these experiments was purchased in the open market and was supposed to be of full strength, which should contain 40 per cent by volume of formaldehyde gas (37 per cent weight U. S. P. standard). The formalin-permanganate method was used to generate the gas in all the experiments, since it has been found that it is the only practicable way of using the gas in mushroom houses. By this method formalin is poured on crystals of potassium permanganate, and this was the procedure in the laboratory experiments, but in the practical application of the method it was found necessary to deposit the potassium permanganate in the receptacles containing the formalin. Chemically pure potassium permanganate in finely divided crystals was used. In each of the experiments the proportions were 100 cubic centimeters of formalin to 50 grams of potassium permanganate.

Exposures of Cultures.

In the laboratory experiments, pure cultures of the fungus were subjected to the direct action of the formaldehyde gas. The cultures were exposed to the gas in Petri dishes and 100-cubic-centimeter flasks.[1]

Fig. 4.—Check culture, experiment 5: Transfer made from culture before it was subjected to formaldehyde gas. From a photograph made 189½ hours after inoculation.

Transfers for checks were made from the cultures to be subjected to the action of the gas immediately before the fumigation and again immediately after fumigation, in order to determine the effect of the formaldehyde gas on the vitality of the fungus. Figure 4 shows the manner in which the inoculations were made in every case in Petri dishes. There were four centers of inoculation, and the amounts transferred from the fumigated cultures were large enough to allow abundant chance for the fungus to grow. In the flask cultures four inoculations were also made.

Results of Fumigation with Formaldehyde on Cultures of the Fungus.

The results of these experiments are given in Table I. The efficacy of formaldehyde in destroying the parasite is clearly shown by these experiments. As stated by McClintic (1906), and also by Patterson, Charles, and Veihmeyer (1910), it seems that higher temperature and humidity increase the fungicidal action of the gas.

[1] The cultures contained Mycogone and Verticillium, as in no instance was it possible to cultivate the Verticillium alone.

TABLE I.—*Results of experiments with formaldehyde gas on cultures of the fungus.*

Experiment. Date.	Experiment. No.	Temperature (°F.) before mixing reagents.	Formalin (c. c.) per 1,000 cubic feet of space.	Age (in days) of culture at time of fumigation.	Number of cultures exposed to formaldehyde gas for— 30 minutes.	60 minutes.	Number of check cultures made.	Growth (period in days)[1] of the fungus in checks and in transfers made from cultures exposed to the gas for 30 and 60 minutes, respectively. Check.	30 minutes.	60 minutes.
1911.										
Jan. 31	1a	55	700	21	12	13	4	3¾	3 in 6; 1 in 8; 2 in 18	1 in 8. 1 in 21.
Jan. 31	1b	55	700	17	11	11	4	3¾	5 in 6; 3 in 7	2 in 6. 2 in 8.
Jan. 31	1c	55	700	7	11	12	4	3¾	6 in 6; 1 in 7; 1 in 14; 1 in 17; 1 in 26	1 in 7. 1 in 21. 1 in 26.
Feb. 8	2	67	700	11	22	23	8	3	1 in 8½; 1 in 20; 1 in 25; 1 in 28	3 in 4½. 2 in 5½. 1 in 9½. 1 in 28.
Mar. 1	3	65	800	16	19	18	8	3	No growth	1 in 5½.
Mar. 10	[2] 4	76	900	23	16	18	10	3½	do	No growth.
Mar. 16	5	58	1,000	12	14	15	13	3½	do	Do.
Apr. 4	6	74	900	17	None.	12	4	4		1 in 38.
Apr. 4	[3] 7	76	300	9	11	11	6	3½	No growth	No growth.
Apr. 14	[4] 8	78	700	11	10	9	5	[5] 4 in 3½	do	Do.
Apr. 20	[6] 9	73	600	13	12	10	6	5 in 3½	1 in 8½; 1 in 26	1 in 8½. 1 in 17. 1 in 20.
Apr. 25	[7] 10	76	500	20	None.	15	6	5 in 3½; 1 in 4½		1 in 10. 1 in 23.

RECAPITULATION OF RESULTS.

Experiment No.	Temperature (°F.) before mixing.	Formalin (c. c.) per 1,000 cubic feet of space.	Age (in days) of culture at time of fumigation.	Percentage of check cultures and transfers from cultures which grew after exposure to formaldehyde gas for stated lengths of time. Checks.	15 minutes.	30 minutes.	60 minutes.	90 minutes.	18½ hours.
10	76	500	20	83.33	42.85		13.33		0
9	73	600	13	83.33		16.67	30	0	0
8	78	700	11	80	0	0	0	0	
1a	55	700	21	100		58.33	15.38		
1b	55	700	17	100		72.72	36.36		
1c	55	700	7	100		90.90	25		
2	67	700	11	100		18.18	34.35		
3	65	800	16	100		0	5.55		
7	76	800	9	100	0	0	0	0	
4	76	900	23	100		0	0	0	
6	74	900	17	100			8.33		
5	58	1,000	12	100		0	0		

[1] The period for growth was reckoned to the time when an indication of growth of the fungus in the transfers first appeared.

[2] In experiment 4, 17 cultures also were subjected for 90 minutes to formaldehyde gas, and the transfers from them showed no growth.

[3] In experiment 7, 12 cultures were also subjected for 15 minutes and 11 cultures for 90 minutes to formaldehyde gas, and the transfers from them showed no growth.

[4] In experiment 8, 10 cultures were also subjected for 15 minutes to the gas and 10 cultures for 90 minutes. None of the transfers grew.

[5] One culture contaminated.

[6] In experiment 9, 12 cultures were also subjected for 90 minutes and 11 cultures for 18½ hours to the gas. There was no growth in the transfers.

[7] In experiment 10, 14 cultures were also subjected for 15 minutes to the gas, and 6 transfers grew in 16 days; 14 cultures also were subjected for 19½ hours and the transfers from them showed no growth.

The total absence of growth in the transfers from the cultures subjected to fumigation and the abundant and vigorous growth in the check cultures were constant and characteristic of this series of experiments.

Treatment with Coal Oil.

Early in the investigation of the problem of this mushroom disease it was learned that certain growers believed coal oil to be effective in destroying the spores of the fungus and checking the spread of the disease. The coal oil was poured on sections in the beds where diseased mushrooms had appeared and was also employed for the disinfection of the hands and tools. In order to demonstrate the efficacy or inefficacy of this treatment a large number of cultures of the fungus were grown on corn meal in 100-cubic-centimeter flasks and subjected to the direct action of the oil. These cultures were of various ages, but all in a state of vigorous growth. An arrangement was made by which the flasks could be inverted over the nozzle of a pipe supplying compressed air and made to pass through a stream of coal oil. The compressed air was turned on and the coal oil sprayed upon the culture. One half of the cultures were removed after the fungus had become covered with a film of coal oil. It was thought that this would be comparable to the condition in a mushroom house where coal oil was sprayed on the bed boards, walls, floors, and ceiling. The remaining cultures were sprayed until they were drenched with oil. In these the coal oil thoroughly penetrated the culture, which was practically an immersion of the fungus in coal oil.

As in the experiments with formaldehyde, transfers were immediately made from the treated cultures. These cultures grew as quickly and as vigorously as the check cultures (transfers made from the cultures before being treated with coal oil). A sufficient number of these experiments were made to demonstrate the inefficacy of coal oil as an agent for controlling this disease.

Treatment with Additional Disinfectants.

Costantin and Dufour (1893*a*) experimented with a variety of chemicals, to note their action on the growth of the fungus in cultures. The experiments were carried on in such a way that the toxic effect of the chemicals could be definitely determined. The following were used: Lysol, thymol (or thymic acid), boric acid, copper sulphate, calcium bisulphite, and milk of lime. These authors range the chemicals in the order of their effectiveness as follows: (1) Lysol (2 per cent solution), (2) thymol (2 per cent solution), (3) copper sulphate (2.5 per cent solution), (4) boric acid (to saturation). The milk of lime which many growers used for cleaning their caves was ineffective in preventing the growth of the disease, and the use of calcium bisulphite is not advised. From these experiments these authors advise the use of a 2 or 2.5 per cent solution of lysol as a spray to disinfect mushroom caves.

The investigators (Costantin and Dufour, 1892*b*, p. 145) described cultural experiments of the parasite, using sulphur dioxid produced by burning sulphur. It was concluded that "sulphur dioxid has a very destructive effect upon the spores of the parasite." Directions are given (Costantin and Dufour, 1893*b*, p. 411) for the fumigation of mushroom caves by burning sulphur. These investigators in a later publication say that the sulphur method of fumigation is attended with such inconvenience that spraying with lysol is preferable (Delacroix, 1900).

The Great Britain Board of Agriculture and Fisheries (1905) recommends the thorough spraying of the house or other structure in which the mushrooms are grown with a solution of sulphate of copper, 1 pound of sulphate to 15 gallons of water, three times at intervals of 10 days. This treatment has been recommended to English growers since 1905 (Gardeners' Chronicle, 1906–1912).

Costantin and Dufour (1893*a*, p. 510) found that copper sulphate had a very feeble antiseptic action on the parasite. In America the attempts to control the disease by this fungicide have been discouraging to the majority of the growers using it.

Costantin (1893*b*, p. 530) and Dufour (Costantin and Dufour, 1893*a*, p. 504), from the results obtained in experiments in a mushroom cave, advised the use of a 2.5 per cent solution of lysol. When the cave is dry, one spraying is said to be sufficient, but if it is very damp two thorough sprayings are to be given. A 2 per cent solution of lysol in water was used to check the spread of the disease in the mushroom bed in an infected cave. Places where the diseased mushrooms appeared in the beds were watered with the solution and the disease destroyed. In one of these places, watered with the disinfectant, a cluster of healthy, normal mushrooms later developed.

So-called "sanitary fluids," of which there are quite a number on the market, composed of coal-tar derivatives, saponified, are of a nature similar to the lysol used abroad.

Several experiments have been made with such fluids. Although the number of these experiments was limited and the results not absolutely conclusive, in view of the previous French experiments with a similar disinfectant it is thought that these sanitary fluids will be effective for the uses mentioned, while the price is not prohibitive.

PRACTICAL EXPERIMENTS TO CONTROL THE DISEASE.

A practical application was made of the information acquired from the results obtained in the laboratory experiments with formaldehyde gas in the inauguration of experiments for the control of the disease. This economic phase of the work received attention during several years. Continuous observations were made of the same houses during this period, but each succeeding year additional houses, with their more or less differing conditions, were added as subjects of study in the practical application of the formaldehyde method for the control of the disease. Experiments were made in fumigating houses with different amounts of formaldehyde, the following proportions being used: 26 fluid ounces of formaldehyde per 1,000 cubic feet, 1 quart of formaldehyde per 1,000 cubic feet, and 3 pints of formaldehyde per 1,000 cubic feet. The proportion of 3 pints to 1,000 cubic feet was found to be more effective and will probably prove the most satisfactory in ordinary practice. In cases in which the leakage was considerable, allowance was made for such loss.

During the course of the present investigation 16 houses were fumigated by the writer or according to his directions. Two of these houses were fumigated at the rate of 26 ounces of formaldehyde per 1,000 cubic feet, five at the rate of 1 quart of formaldehyde per 1,000 cubic feet, and nine at the rate of 3 pints of formaldehyde per 1,000 cubic feet.

Two houses which were total failures the season previous to fumigation, after treatment produced crops which the grower reports as follows: "I believe that I never had a finer or more promising house or better mushrooms." The results of fumigation were successful in all cases in which the proper sanitary methods were observed to prevent reinfection of the houses.

From the writer's observations of the results of these experiments with fumigation and the satisfaction expressed by the growers in the course of conversation or correspondence as to the efficacy of the treatment, the important rôle of formaldehyde as an agent in controlling the mushroom disease seems practically demonstrated.

MEASURES OF CONTROL.

As a result of the present investigation of the Mycogone disease of mushrooms, the following measures may be advised for the control of the fungus. The treatment is more or less prophylactic in its nature and seeks rather to prevent the appearance or spread of the disease than to eradicate the fungus after it has actually made its appearance.

Sanitation Necessary in Relation to the Disease.

Too much emphasis can not be placed upon the danger from the fungus, because of its highly infectious nature. The remarkable rapidity with which the fungus is propagated and the great vitality possessed by the spores, as shown in the preceding pages, make it absolutely essential to observe great care in the construction of new beds or in passing from an infected to a noninfected bed. The ways in which the spores may be carried from place to place are numerous. They may be contained in the manure or soil for the casing of the beds, in particles of earth or manure adhering to the boots and shoes of the workmen, or they may be present on tools and implements used in the mushroom houses. Wind and insects, especially the mushroom fly, are probably active agents in the distribution of the disease.

It is a deplorable fact that there are growers who allow diseased mushrooms to decay on the beds. There is in many cases so much discouragement due to losses occasioned by the disease that no effort is made to clean off the beds, the growers being content to pick what few normal mushrooms they can and avoid the labor necessary to suitably dispose of diseased specimens.

Figure 5 shows a photograph of a bed which has been practically exhausted, no normal mushrooms being produced. The grower has allowed the diseased masses to remain and decay and these will produce millions of spores, which will become a menace to new beds. These spores will become mixed with the manure and earth when the beds

FIG. 5.—Diseased mushrooms left to decay upon the beds to become a menace to future crops.

are removed and, if not suitably disposed of, may be introduced into the house when new beds are made.

All diseased material should be picked off as soon as it makes its appearance. The labor of keeping the beds clear of the diseased specimens will be repaid many times over in preventing the spread of the malady. An important measure for the control of the disease is to prevent the production of spores of the parasite.

Places in the beds where the fungus appears may be treated with either of the disinfectants mentioned, formalin or one of the "sanitary fluids," to prevent the spread of the disease. Diseased mushrooms picked from beds should be soaked with a disinfectant. For this purpose a solution of 1 gallon of formalin to 1 barrel of water (45 gallons) should be used. The only reason for not using formaldehyde solution is the discomfort in handling it. Its fungicidal action against the disease has proved to be effective. In place of the formaldehyde solution, one containing 5 per cent—a gallon to a barrel of water—of one of the sanitary fluids composed of coal-tar derivatives will be satisfactory. This percentage is higher than that commercially recommended.

When the material is removed from the bed at the completion of the production of the crop, it should be immediately removed to places where there will be no possibility of bringing the disease back into the houses. The Mycogone disease, as far as is known, does not affect other cultivated crops. The old compost may therefore be used as a fertilizer, but it should be sold only to farmers who will carry it to a distance and to a locality where mushroom cultivation is not practiced.

The ground in the vicinity of the houses, the composting yard, and places with which the diseased materials have come in contact must be thoroughly sprayed with one of the disinfectants. If it is necessary to place the new manure or soil on ground where the old compost from diseased houses has rested, it will be necessary to give several such sprayings.

All tools, carts, wagons, and wheelbarrows which have been used to handle the infected materials must be thoroughly treated with the disinfectant.

Soil for the casing of the beds and for mixing with the manure must be selected from a place which has not been in contact with the disease.

The houses which have been fumigated should be kept closed until precautions to prevent the reentrance of the disease have been taken.

Directions for Fumigating Mushroom Houses.

Preparatory to fumigation, the houses should be completely cleaned of all old bedding material and thoroughly swept. The proper method for the disposal of this material has already been described.

A warm, moist day should be selected for fumigation, as the fungicidal effect of the gas is greater under such conditions. To this end, the house should be thoroughly sprayed with water and kept warm for about a week or ten days. To insure sufficient humidity, this process should be repeated the day before the fumigation is to be performed. The houses should be closed and sealed and made as nearly air-tight as possible by pasting paper over all cracks and filling up all openings, thus preventing the escape of the gas. If care is not exercised to prevent leakage of the gas, the fumigation may be rendered ineffective. The same grade of formaldehyde (or commercial formalin) as that used in the experiments with pure cultures of the fungus is advised for practical work.

Three pints of formalin should be allowed for every 1,000 cubic feet of space, the reagents being used in the proportion of 1 pint of formalin to one-half pound of potassium permanganate. In houses

24 by 100 feet, the usual size of mushroom houses, at least three receptacles should be used in which to generate the gas. It does not matter what the material of the receptacles may be, for the formalin has no corrosive action, but the heat of the chemical reaction, when potassium permanganate (permanganate of potash) is added to the formalin, might break glass receptacles. Half barrels, wash tubs, and iron or earthen receptacles are suitable, but it is advisable to select containers in which the diameter of the top is greater than that of the base. The formalin should cover the potassium permanganate when it is placed in the receptacle, which should be deep enough to insure the formalin from splashing over as a result of the vigorous chemical action.

The proper amount of formalin is measured and divided among the number of receptacles to be used in each house, while the proper proportion of potassium permanganate to be added to the formalin in each receptacle is carefully weighed out into paper or cloth bags. It will be found more satisfactory and the possibility of error may be avoided if like amounts of formalin and potassium permanganate are placed in each receptacle. If convenient, receptacles of a uniform size should be selected.

The weighing and measuring of the chemicals should be accomplished as quickly as possible after the receptacles containing the formalin are placed in the house. It is advisable to weigh the potassium permanganate into the bags first and then to measure the formalin for the respective receptacles, since considerable gas will be given off from the formalin and the house being almost air-tight, extreme physical discomfort due to the formaldehyde gas might result. The receptacles containing the formalin are then placed in position in the aisles of the house. In average-sized houses it will be sufficient to place the receptacles in the center aisle, but in larger houses the gas must be more evenly distributed by placing some of the receptacles in the several aisles. There will be required as many persons to place the bags of potassium permanganate in the formalin receptacles as the number of aisles in which the receptacles have been placed.

A bag of potassium permanganate is placed beside each receptacle containing the proportionate amount of formalin. When everything is ready, the operator in each aisle, if there are receptacles in more than one aisle, goes to the farthermost receptacle in that aisle and places the bag of potassium permanganate in the formalin, the operation being simultaneous in each aisle. Egress is made through the door at the end of the aisle, which is quickly closed and tightly sealed.

The operation should be accomplished as quickly as possible, and care should be taken to prevent accidents, for inhaling large quantities of the gas may prove injurious. Formaldehyde has a distressing effect upon the eyes, and also attacks the mucous membranes, with consequent discomfort.

The potassium permanganate may be placed in the receptacles first, which should be of selected size, so that it will just cover the base of the receptacle. This was the method followed in the cultural experiments, but, as already stated, for general practice it was found more convenient to place the formaldehyde in the receptacles first.

The formalin-permanganate method of fumigation differs radically from other methods. The potassium permanganate is decomposed by a part of the formalin, and the heat of this chemical reaction serves to liberate formaldehyde gas.

Formaldehyde gas is *explosive* when in a confined place, such as a mushroom house; consequently, *all lights must be kept away from the houses while they are being fumigated.* Even after the receptacles containing the formalin are placed in the houses, they *should not be entered by persons with lights.*

The houses should be kept closed for at least 24 hours. If possible, they should be unopened until just before the new beds are to be installed, thus preventing any chance of their being infected meantime. Under no circumstance should the houses be opened until the manure which had been taken from them has been removed and the ground where it was placed thoroughly disinfected in the manner described.

CONCLUSIONS.

The disease of cultivated mushrooms is the cause of extensive losses to growers in this country, who state that unless precautions are taken to prevent its spread it will necessitate the abandonment of the industry in infected localities.

The disease of cultivated mushrooms apparently is the same as that which has caused great losses to foreign mushroom growers for many years.

This disease is caused by a fungus, a species of Mycogone, which has two forms of spores, one possessing thin and the other thick walls. Experiments prove that the thick-walled spores retain their vitality under ordinary cultural conditions for considerable periods of time. A moist atmosphere is essential for the growth of the fungus, as moisture rather than heat favors luxuriant growth. Cultures kept in a dry place were found to retain their vitality about 18 months. This would indicate that under natural conditions the life of the spores would be much longer.

The removal of the diseased mushrooms as soon as they appear will prevent the production of the thick-walled spores and thus lessen the spread of the disease.

As the disease is carried by many different means, the greatest care must be taken to prevent the infection of clean houses. There are, in general, two ways in which infection may take place: (1) It may be introduced into the house by means of the spawn and (2) the manure or soil for the beds may contain spores of the fungus. In the first case, the disease becomes evident as soon as the mushrooms begin to make their appearance, and all portions of the beds are affected. In the second case, beds may become infected by spores from a previously diseased crop. Air currents free these spores from crevices or wherever they may have lodged and thus assure a recurrence of the trouble; insects may carry spores from other diseased beds, or from diseased material which has been allowed to remain outside the houses, or spores may be carried on clothing or tools. When the spores of the parasite are introduced in such a manner, the disease may make its appearance a considerable time after the crop has begun to bear.

The abandonment of diseased houses for less than three years will be insufficient to rid them of the parasite, and a period of more than three years may be necessary.

Formaldehyde-gas fumigation and the observance of proper sanitary measures should be employed.

Formaldehyde gas, even in small quantities, retards the growth of the fungus, and when sufficiently strong will destroy the spores. A rate of 3 pints of formaldehyde or formalin per 1,000 cubic feet should be used, in the proportion of 1 pint of formalin to one-half pound of potassium permanganate.

Fumigation will control the disease in the houses, but will not keep them free, since bringing infected material, tools, etc., into the houses will certainly start the disease anew; therefore every precaution should be taken to prevent the reinfection of the houses after they have been fumigated.

Coal oil has no effect upon the spores of the parasite.

Diseased material should be removed from the houses immediately and treated with a disinfectant, preferably a solution of 1 gallon of formalin to about 45 gallons of water. This disinfectant should be used to spray all places where diseased material has been. Tools and conveyances should also be treated.

The disease is highly infectious, and the measures to be taken are more prophylactic than palliative in their nature.

Certain questions are yet to be solved concerning the life history of the fungus, such as the development of a perfect stage, but the method evolved for the control of the disease has proved effective and has resulted in saving large sums to mushroom growers.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 128

Contribution from the Bureau of Biological Survey, Henry W. Henshaw, Chief.
September 25, 1914.

DISTRIBUTION AND MIGRATION OF NORTH AMERICAN RAILS AND THEIR ALLIES.

By Wells W. Cooke,
Assistant Biologist.

INTRODUCTION.

The North American rails and their allies, the cranes, gallinules, coots, and others, are considered game birds in many localities, but until within the last few years they have received scant protection. As a matter of fact they include among their number several species that are not only of harmless habits but of great food value. This is particularly true of the sora, or Carolina rail, which until recently has existed in immense numbers in the marshes of the Atlantic States, and which not only has been a favorite object of pursuit by sportsmen but also has been regarded as a highly prized table delicacy.

Another species, than which none more striking exists in North America, is the stately white crane. This bird used to stalk over the prairies but is now almost extinct, and a few more years will probably witness the passing of the last individual. The draining of the Everglades probably will mark the end also of the contingent of its smaller relative, the sandhill crane, which nests in Florida. While the destruction of such birds is to be deplored it seems to be a necessary concomitant of the settlement of the wide areas they once called home. A large bird that furnishes meat of a high grade can not be expected to survive long in a thickly settled country. Owing to their fine appearance, harmless habits, and economic worth, it is highly desirable to withdraw all cranes from the list of game birds and preserve as long as possible the few now remaining.

Rails differ markedly from cranes in appearance and habits, although they belong to the same family. Chiefly marsh or meadow breeding birds, they spend most of their time well concealed in rank swamp vegetation, where they are out of harm's way. Several of the species are few in numbers, but they are so secretive that they

Note.—This bulletin aims to give precise information as to the ranges of the several species of North American rails and their allies, the cranes, gallinules, coots, and others, especially in regard to breeding ranges and migrations; and to furnish data sufficient to serve as a basis for protective legislation for the species by States in which they are found.

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probably maintain their numbers in spite of persecution. The one striking exception is the sora, or Carolina rail, for which a special plea needs to be entered.

Considered a game bird in many parts of the United States, the sora has rapidly decreased in numbers. Many hunters are fond of the sport of rail shooting, and since each hunter requires a boat and a pusher, the rail-shooting season is an important factor in the total yearly income of a large number of boatmen in the neighborhood of rail marshes.

The sora was originally the most abundant of the rails, and is still able to care for itself during the breeding season, when it is thinly scattered over an immense area of fresh-water marshes. During migration, however, it betakes itself to tidewater marshes and here falls an easy prey to the hunter. Each high tide forces the bird from its safe retreat in thick grass or bushes and affords the hunter a chance to pursue his game in the open, when the number of sora killed is almost past belief. A long-noted resort for the sora is the flat land near the mouth of the James River, Va. Here at the height of the fall migration in September the reeds used to be fairly alive with countless thousands of these birds. That their number is now sadly reduced can easily be understood from the hosts that have been shot on these marshes. Two men in two days, September 15–16, 1881, killed 1,235 of the birds, while as many as 3,000 have been shot in a single day on a marsh of hardly 500 acres. In the light of such figures no one need ask what is becoming of the game birds or what is their probable fate. Immediate steps should be taken to decrease the bag limit in order to prevent the destruction of the species.

The sora is a game bird that should be especially fostered. Its habits are absolutely harmless; it breeds only in places that are not suitable for agricultural purposes; it will live and thrive in marshy spots too small to harbor any other species of game bird; and it is so widely distributed and so capable of adapting itself to a wide range of conditions, that if given a fair chance and not too severely harassed during the shooting season, it will survive in abundance as a game bird long after many other species have succumbed before the advance of intensive agriculture.

While the salt-marsh breeding rails have not been so severely persecuted as the sora, they are numerous enough and important enough both for food and sport to warrant more effective protection than has hitherto been afforded them. They should at least be allowed to breed in peace, and robbing their nests should be prohibited.

A word may be said also in favor of the much despised coot. Many hunters class this bird with the crow as regards edible qualities. However, those who have tasted coot only in winter or spring after it has fed for many weeks on the animal life of the salt-water marshes, would not recognize the taste of the bird in October in northern Minnesota, after it has been fattened on that best of all duck foods, wild rice. But everywhere in the United States coots and gallinules should be recognized by law and their killing should be forbidden during the closed season on ducks, if for no other reason than that their slaughter may not be used as a blind to hide the killing of the more valuable ducks.

DISTRIBUTION.

The North American rails and their allies include 36 species and 8 subspecies, a total of 44 forms. Twenty-one of these (16 species and 5 subspecies) are found only in the West Indies and Middle America, and two are Eastern Hemisphere species that are casual or accidental in North America. This leaves 18 species and 3 subspecies, or 21 forms, that occur in the United States.

SOUTHERN FORMS NOT RANGING NORTH TO THE UNITED STATES.

Cuban king rail (*Rallus elegans ramsdeni*).
Mexican king rail (*Rallus tenuirostris*).
Bahama clapper rail (*Rallus crepitans coryi*).
Caribbean clapper rail (*Rallus longirostris caribaeus*).
Cuban clapper rail (*Rallus longirostris cubanus*).
Yucatan clapper rail (*Rallus pallidus*).
Spotted rail (*Limnopardalus maculatus*).
Lawrence wood rail (*Aramides axillaris*).
Cayenne wood rail (*Aramides cajanea*).
Mangrove wood rail (*Aramides albiventris*).
Nicaragua wood rail (*Aramides plumbeicollis*).
Red rail (*Amaurolimnas concolor*).
Mexican yellow rail (*Porzana goldmani*).
Yellow-bellied rail (*Porzana flaviventris*).
Rufous rail (*Porzana rubra*).
Ash-headed rail (*Creciscus cinereiceps*).
White-throated rail (*Creciscus albigularis*).
Wandering rail (*Creciscus exilis vagans*).
Caribbean coot (*Fulica caribaea*).
American finfoot (*Heliornis fulica*).
Guatemalan sun bittern (*Eurypyga major*).

EURASIAN FORMS ACCIDENTAL IN GREENLAND.

Spotted crake (*Porzana porzana*).
European coot (*Fulica atra*).

FORMS RANGING IN THE UNITED STATES.

Whooping crane (*Grus americana*).
Little brown crane (*Grus canadensis*).
Sandhill crane (*Grus mexicana*).
Limpkin (*Aramus vociferus*).
King rail (*Rallus elegans*).
Belding rail (*Rallus beldingi*).
California clapper rail (*Rallus obsoletus*).
Light-footed rail (*Rallus levipes*).
Clapper rail (*Rallus crepitans crepitans*).
Louisiana clapper rail (*Rallus crepitans saturatus*).
Florida clapper rail (*Rallus crepitans scotti*).
Wayne clapper rail (*Rallus crepitans waynei*).
Virginia rail (*Rallus virginianus*).
Sora, or Carolina rail (*Porzana carolina*).
Yellow rail (*Coturnicops noveboracensis*).
Black rail (*Creciscus jamaicensis*).
Farallon rail (*Creciscus coturniculus*).
Corn crake (*Crex crex*).
Purple gallinule (*Ionornis martinicus*).
Florida gallinule (*Gallinula galeata*).
Coot (*Fulica americana*).

MIGRATION.

Rails and their allies include both migratory and nonmigratory forms. Most of the salt-water species remain in the same marshes the entire year, while the greater number of those breeding near fresh water perform longer or shorter migrations. Much misunderstanding has arisen in regard to the powers of flight of some of the species. The flight of the sora is so slow and labored and the bird seems so reluctant to use its wings that some writers have supposed that it was unable to fly long distances and that its migration was therefore a series of short flights or even performed on foot. As a matter of fact the sora is among the long-distance migrants, the most northern breeders traveling not less than 2,500 miles to the nearest winter home; and those wintering south of the Equator being at least 3,000 miles from the nearest breeding grounds. Thousands make the hundred-mile flight between Florida and Cuba, and there is reason to believe that many individuals easily achieve the 500-mile passage from Florida to Yucatan, and the equally long journey from the West Indies across the Caribbean Sea to South America.

As in previous bulletins of this nature,[1] the data on distribution and breeding have been collected from both published and unpublished sources; the migration data are taken principally from reports of observers scattered all over the United States and Canada, who for 30 years have been furnishing the Biological Survey extensive records of bird movements.

NORTH AMERICAN RAILS AND THEIR ALLIES.

WHOOPING CRANE. *Grus americana* (Linnaeus).

Range.—North America, from northern Mackenzie to Florida and central Mexico.

Breeding range.—Many years ago, when the whooping crane was common, it was known to nest north to Great Slave Lake (Coues) and south to Oakland Valley, Iowa (eggs in U. S. National Museum), the breeding range being a northwest and southeast strip 1,500 miles long by less than 300 miles wide. The species probably nested over a much wider area, since Hearne says that in his day, about 1770, it occurred on the coast of Hudson Bay [near Fort Churchill], and on May 25, 1865, Macfarlane saw it at Fort Anderson, Mackenzie, and about the same time Ross saw it at Fort Simpson, Mackenzie. It nested east of Dubuque, Iowa (Coues), Mille Lacs, Minn. (Trippe), and Oak Point, Man. (Small); and west to Spirit Lake, Iowa (Mosher), Herman, Minn. (Roberts and Benner), Larimore, N. Dak. (Eastgate), Qu'Appelle, Sask. (Hind), and Stony

[1] Bul. 45, Biol. Surv., U. S. Dept. Agr., 1913, "Distribution and Migration of North American Herons and Their Allies," et al.

Plain, Alta. (Stansell). At the present time the species has probably ceased to breed anywhere in the United States or Manitoba, and the few remaining individuals—for the species is almost extinct—spend the summer in southern Mackenzie and the northern parts of Alberta and Saskatchewan.

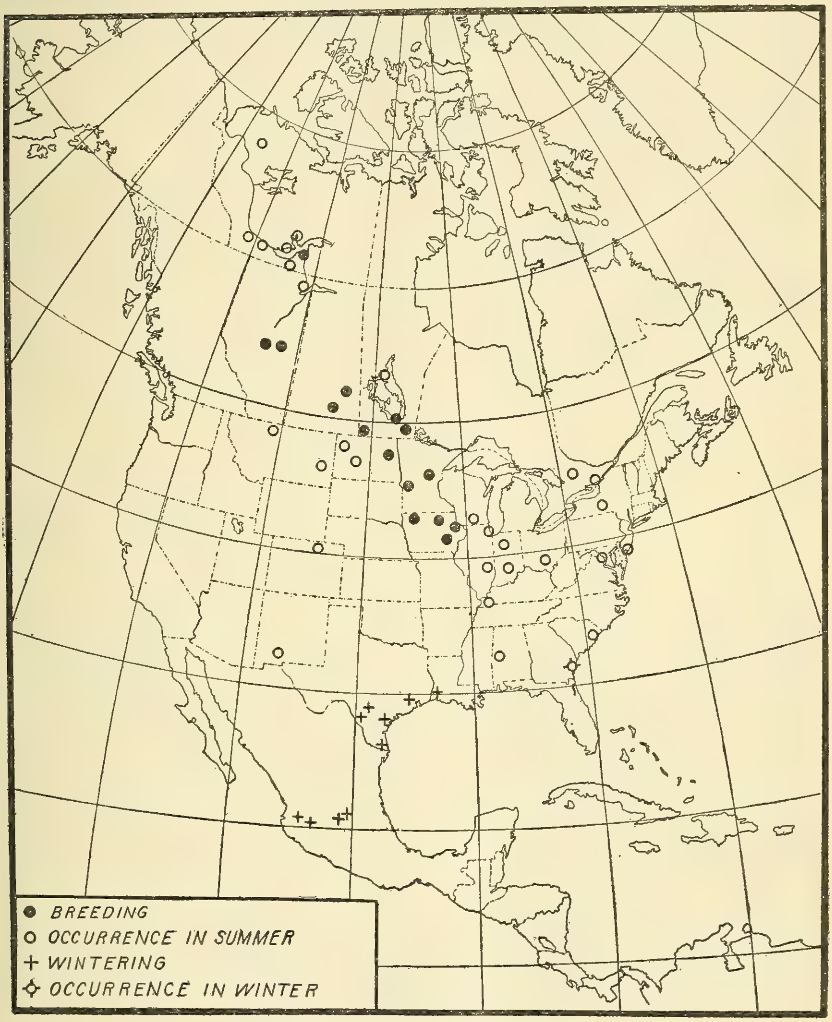

FIG. 1.—Whooping crane (*Grus americana*).

Winter range.—The winter range is rather restricted, extending from southern Louisiana (Audubon), along the coast of Texas to northern Tamaulipas (Nelson), La Barca, Jalisco (Goldman), and Silao, Guanajuato (Nelson). Formerly the species ranged in winter eastward to western Florida (Nuttall).

Migration range.—The whooping crane seems to have had a pronounced southeastward migration in the fall, bringing it to Emsdale, Ont. (Fleming), Yarker, Ont. (Ewart), Cayuga Lake, N. Y. (Eaton), and Beesleys Point, N. J. (Turnbull). There are good grounds for believing that in early colonial times it wandered not rarely to Vermont and Massachusetts. It ceased to visit New England a century ago, and there are hardly a half dozen records of its occurrence in the last 25 years east of Lake Huron and the Allegheny Mountains.

The whooping crane probably was never a common visitor to the South Atlantic States. Audubon's records of the crane in that part of the country refer to the sandhill crane, but one was seen about 1850 on the Waccamaw River, S. C. (Wayne), and there was a specimen in the museum of the Academy of Natural Sciences of Philadelphia, sent from St. Simon Island, Ga.

The whooping crane has wandered westward a few times to Big Sandy, Mont., May 1–5, 1903 (Coubeau); Terry, Mont., October 5, 1904 (Cameron); Loveland, Colo. (Smith); and southern New Mexico (Henry).

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
St. Louis, Mo	3	Mar. 22	Mar. 17, 1884
Stotesbury, Mo			Mar. 9, 1894
Indianola, Iowa	4	Mar. 24	Mar. 18, 1901
Storm Lake, Iowa	4	Mar. 25	Mar. 22, 1886
Heron Lake, Minn	5	Mar. 28	Mar. 20, 1889
Bonham, Tex	3	Mar. 24	Mar. 23, 1890
East-central Kansas	4	Mar. 18	Mar. 7, 1887
Southeastern Nebraska	5	Mar. 20	Mar. 16, 1890
Northeastern Nebraska	5	Apr. 3	Mar. 23, 1900
Harrison, S. Dak. (near)	3	Apr. 5	Mar. 25, 1890
Northeastern North Dakota	8	Apr. 10	Apr. 5, 1885
Loveland, Colo	2	Apr. 12	Apr. 8, 1889
Aweme, Man	8	Apr. 12	Apr. 6, 1900
Indian Head, Sask. (near)	4	Apr. 23	Apr. 19, 1904
Stony Plain, Alta			May 21, 1909
Hay River, Mackenzie			May 12, 1908
Willow River, Mackenzie			May 13, 1905
Fort Rae, Mackenzie			May 15, 1860
Fort Anderson, Mackenzie			May 25, 1865
Brownsville, Tex			Apr. 1, 1877
Bonham, Tex	3	Apr. 5	Apr. 9, 1886
Bay St. Louis, Miss			Apr. 15, 1902
East-central Kansas	4	Apr. 15	Apr. 18, 1891
Eastern Nebraska	4	May 10	May 16, 1890
Harrison, S. Dak	2	Apr. 30	May 15, 1891

Eggs have been taken April 25, 1868, at Dubuque, Iowa (specimens in U. S. National Museum); May 2, 1882, at Clear Lake, Iowa (Goss); May 26, 1894, near Eagle Lake, Hancock County, Iowa (Anderson); and May 16, 1900, at Yorkton, Sask.

Fall migration.

Place.	Number of years' records.	Average date of fall arrival.	Earliest date of fall arrival.
Southeastern South Dakota	3	Sept. 8	Sept. 8, 1891
Eastern Nebraska	6	Oct. 6	Sept. 19, 1891
Indianola, Iowa			Sept. 4, 1902
Hickman, Ky			Aug. 26, 1886
Bonham, Tex			Oct. 8, 1888

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Aweme, Man	3	Oct. 10	Oct. 12, 1904
Harrison, S. Dak	2	Oct. 29	Nov. 1, 1891
Eastern Nebraska	3	Oct. 26	Nov. 12, 1890
Onaga, Kans			Oct. 18, 1907
Heron Lake, Minn			Nov. 13, 1885
Decatur County, Iowa			Nov. 12, 1871
Bonham, Tex	3	Nov. 19	Nov. 22, 1888

LITTLE BROWN CRANE. *Grus canadensis* (Linnaeus).

Range.—North America from the Arctic islands to central Mexico.

Breeding range.—The little brown crane is the northern representative of the common sandhill crane of the United States, and breeds north to Ponds Bay, Baffin Land, latitude 73° (McClintock), Bay of Mercy, Banks Land, latitude 74° (Armstrong), and Colville River, Alaska, latitude 71° (Murdock); and ranges north in migration to Point Barrow (Stone). It breeds west to Kotzebue Sound, Alaska (Grinnell), Semiavine Strait, Siberia (Nordenskjold), Lawrence and Matthew Islands, Alaska (Nelson); and migrates still farther west to the Near Islands, Alaska (Turner). The breeding range extends south to the Nushagak River, Alaska (McKay), Big Island, Mackenzie (Coues), and near Cape Eskimo, Keewatin (Preble); and east to Southampton Island, Keewatin (Eifrig), and Igloolik, Melville Peninsula (Parry). The summer home therefore is a parallelogram, 2,500 miles from east to west and one-third as much from north to south.

Winter range.—Compared with the above outlined breeding range, the little brown crane occupies a comparatively small area during the winter season, extending from San Patricio, Tex. (Sennett), to Rio Verde, San Luis Potosi (Allen), Silao, Guanajuato (Nelson), and La Barca, Jalisco (Nelson and Goldman). A specimen was taken at San Rafael Mission near San Francisco, Cal., in January (Buturlin), but this probably was an accidental occurrence.

Migration range.—The little brown crane is a migrant in the region of the Rocky Mountains and the Great Plains lying immediately between the summer and the winter homes, but even here the records are few and far between, owing to the difficulty of distinguishing this species from the more common sandhill crane. The normal migration range may be said to extend east to Manitoba and

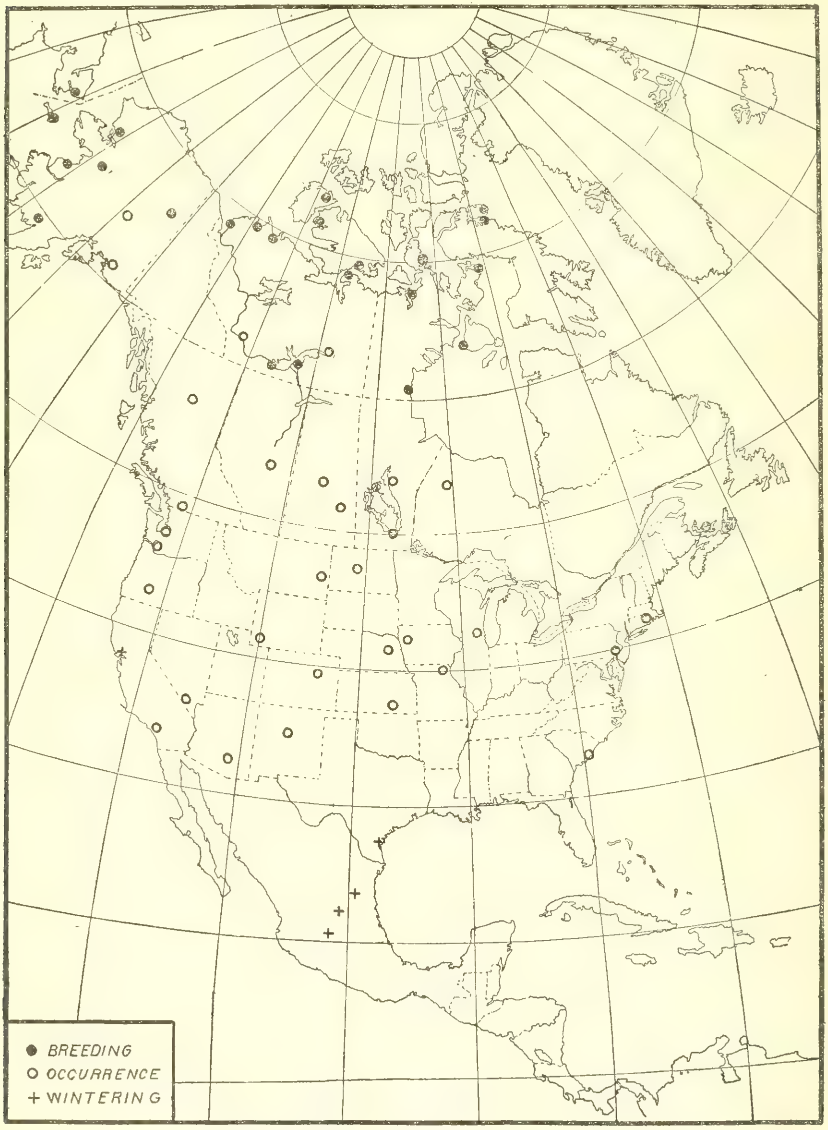

FIG. 2.—Little brown crane (*Grus canadensis*).

Iowa, beyond which wanderers have been recorded from Trout Lake, Keewatin (Murray); near Johnstown, Wis. (Kumlien and Hollister); Clark County, Mo. (Widmann); Alexander, Prince Edward

Island, September 22, 1905 (Moore); Natick Hill, R. I., October 9, 1889 (Howe and Sturtevant); and near Mount Pleasant, S. C., October 18, 1890 (Wayne). The species is rare on the Pacific slope, but has been noted at Chilliwack, B. C. (Brooks); Roy, Wash. (Thayer); Fort Klamath, Oreg. (Merrill); Ash Meadows, Nev. (Fisher); and Los Angeles, Cal. (Grinnell).

Spring migration.—The arrival of the species in spring has been noted in Clark County, Mo., April 10, 1896 (Widmann); Whiting, Iowa, April 6, 1886 (Anderson); near Johnstown, Wis., April 4, 1894 (Kumlien and Hollister); Portage la Prairie, Man., May 5, 1898 (Atkinson); Carlton House, Sask., April 28, 1827 (Richardson); Indian Head, Sask., April 28, 1910 (Lang); Fort Vermilion, Alta., April 24, 1906 (White); Hay River, Mackenzie, May 1, 1908 (Jones); Fort Resolution, Mackenzie, May 7, 1860 (Kennicott); Fort Providence, Mackenzie, April 28, 1905 (Jones); Fort Simpson, Mackenzie, May 9, 1904 (Preble); Felix Harbor, Franklin, latitude 70°, June 4, 1830 (Ross); Igloolik, Franklin, latitude 69°, June 25, 1823 (Parry); Los Angeles, Cal., March 21, 1904 (Grinnell); Ash Meadows, Nev., March 10, 1891 (Fisher); Okanogan Landing, B. C., April 20, 1906 (Brooks); Fort Kenai, Alaska, May 4, 1869 (Bischof); St. Michael, Alaska, May 7 (Nelson); near Kigulik Mountains, Alaska, May 10, 1905 (Anthony); Kowak River, Alaska, May 14, 1899 (Grinnell); Point Barrow, Alaska, June 1, 1883 (Murdock); and Bay of Mercy, Franklin, middle of May, 1852 (Armstrong).

If these isolated records represent the average dates of migration, then the little brown crane occupies about 65 days in passing the 2,800 miles from southern California to Banks Land, an average of about 40 miles a day or scarcely an hour's flight.

Eggs have been found at St. Michael, Alaska, May 27, 1879 (Nelson); Kowak River, Alaska, June 14, 1899 (Grinnell); and young just hatched at Montreal Island, Mackenzie, August 2, 1834 (King).

Fall migration.—Little brown cranes that had nested in Siberia were observed August 18, 1880, crossing Bering Strait to Alaska (Bean), and this probably represents about the beginning of the fall migration. The birds continue to pass south for a month and the last one seen is reported on Kowak River, September 4, 1898 (Grinnell); St. Michael, Alaska, September 27, 1880 (Nelson); Fort Reliance, Mackenzie, September 14, 1907 (Seton); near Athabasca Landing, Alta., September 22, 1903 (Preble); Terry, Mont., October 10, 1898 (Cameron); Okanogan Landing, B. C., September 22, 1888 (Brooks); Edmonds County, S. Dak., October 22, 1883 (specimen in U. S. National Museum); Glendo, Wyo., October 7, 1898 (Jesurun); and Bee County, Tex., October 25, 1887 (Sennett).

SANDHILL CRANE. *Grus mexicana* (Müller).

Range.—North America from southern Canada to Florida, Cuba, and Mexico.

Breeding range.—The sandhill crane has two distinct and widely separated breeding areas. The smaller includes Cuba (Gundlach),

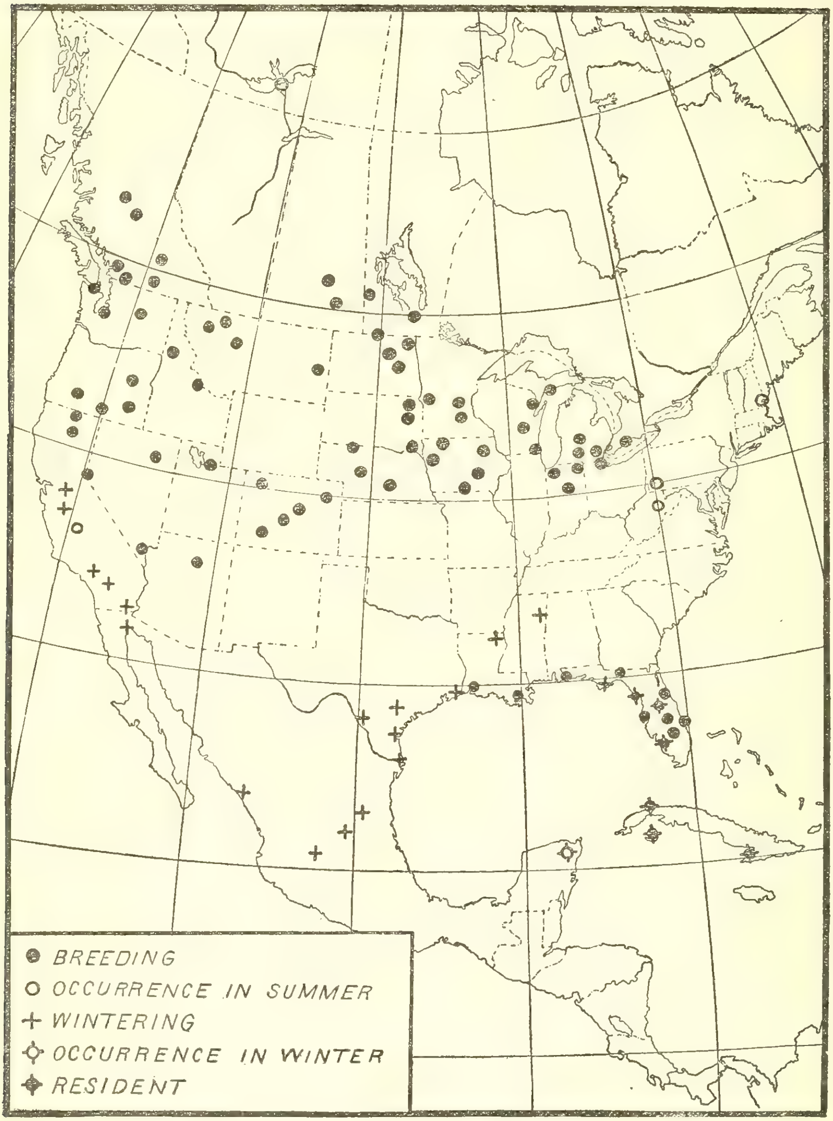

FIG. 3.—Sandhill crane (*Grus mexicana*).

Isle of Pines (Gundlach), and southern Florida north to Waukeenah (Wayne), and Lake Monroe (Bryant). It has been known to nest in the Okefenokee Swamp, Ga. (Wayne); it nested in 1911 near

Perdido Bay, Ala. (Gutsell), and it also breeds at Houma, La. (Wurzlow), and, as late as 1907, at Calcasieu Pass, La. (Kopman).

The larger breeding area extends north to near Rondeau, Ont. (McIlwraith), Morrice, Mich. (Brownell), Vans Harbor, Mich. (Van Winkle), Mille Lacs, Minn. (Trippe), Oak Point, Man. (Small), Shell River, Man. (Calcutt), Big Quill Lake, Sask. (Barnes), Midvale, Mont. (Bailey), 158-Mile House, B. C. (Brooks), and Strait of Juan de Fuca, Wash. (Cooper). The species is definitely known to have nested south to Chicago Junction, Ohio (Jones), Carroll County, Ind. (Sterling), Decatur County, Iowa (Trippe), Alda, Nebr. (Powell), Animas Park, Colo. (Drew), Mormon Lake, Ariz. (Mearns), Independence Valley, Nev. (Hoffman), near Carson City, Nev. (Ridgway), and Fort Crook, Cal. (Coues). Thus at the present time the two breeding areas are separated by a district more than 600 miles wide in which the species does not breed. It is probable that in the early days of the settlement of the Mississippi Valley, when the species was very abundant, it nested somewhat farther south, almost if not quite to the Ohio River. Its numbers have decreased decidedly in the last 30 years, and it is now rare as a breeder in the southern half of the above-defined breeding range, although within the last 10 years it has nested in southern Michigan (1907), northern Indiana (1905), northern Iowa (1907), northwestern Nebraska (1904), and central Colorado (1903).

Winter range.—The sandhill cranes that nest in Louisiana, Florida, and Cuba are probably nonmigratory, while their number in Louisiana is probably augmented during the winter by migrants from the north. The species also winters along the whole coast of Texas and south in Mexico to Hacienda Angostura, San Luis Potosi (Jouy), Guanajuato (Duges), La Barca, Jalisco (Nelson and Goldman), and Mazatlan, Sinaloa (Lawrence). The winter range includes southern California north to Pasadena (Daggett) and, in the early days, to the valleys of central California (Belding). Formerly a few wintered north to Waverly, Miss. (Young), and Mer Rouge, La. (Hollister), while 70 years ago many wintered along the Rio Grande north to Socorro, N. Mex.

Migration range.—The sandhill crane has been noted a few times east of its breeding range, north to Beaumaris, Ont. (Fleming); Brockport, N. Y. (Bruce); Lunenburg, Vt. (Perkins and Howe); Wakefield, N. H. (Allen); Waynesburg, Pa. (Jacobs); Washington, D. C. (Coues); and Waccamaw River, S. C. (Wayne).

It seems probable that in colonial days the sandhill crane was not uncommon as a migrant throughout most of eastern United States from New York and southern New England southward.

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Newport, Ark			Mar. 19, 1884.
Eubank, Ky	2	Mar. 12	Mar. 8, 1894.
Bolton, Mo	11	Mar. 23	Mar. 2, 1908.
St. Louis, Mo			Mar. 4, 1882.
Mount Carmel, Ill			Mar. 1-4, 1863-66
Tampico, Ill	6	Mar. 25	Mar. 8, 1887.
Bicknell, Ind	2	Mar. 20	Mar. 18, 1906.
English Lake, Ind			Mar. 7, 1894.
Petersburg, Mich	9	Mar. 15	Mar. 8, 1892.
Locke, Mich	19	Mar. 21	Feb. 19, 1857.
Grinnell, Iowa	5	Mar. 20	Mar. 11, 1890.
Storm Lake, Iowa	4	Mar. 20	Mar. 12, 1887.
Milford, Wis	5	Mar. 19	Mar. 13, 1851.
Elk River, Minn	5	Apr. 2	Mar. 22, 1887.
Heron Lake, Minn	5	Apr. 4	Mar. 30, 1884.
White Earth, Minn	4	Apr. 4	Mar. 27, 1881.
Grape Vine, Tex	14	Mar. 18	Mar. 4, 1892.
Gainesville, Tex. (near)	4	Mar. 14	Mar. 2, 1887.
Caddo, Okla			Feb. 26, 1884.
Richmond, Kans	5	Mar. 23	Mar. 11, 1885.
Topeka, Kans	4	Mar. 24	Mar. 16, 1891.
Onaga, Kans	5	Mar. 25	Feb. 14, 1896.
Syracuse, Nebr	5	Mar. 26	Mar. 12, 1898.
Badger, Nebr	3	Apr. 6	Mar. 26, 1902.
Southeastern South Dakota	11	Apr. 6	Mar. 26, 1910.
Argusville, N. Dak	13	Apr. 16	Apr. 8, 1895.
Larimore, N. Dak	10	Apr. 16	Apr. 12, 1890.
Bathgate, N. Dak	5	Apr. 15	Apr. 5, 1894.
Aweme, Man	13	Apr. 14	Apr. 6, 1905.
Shell River, Man	3	Apr. 15	Apr. 14, 1891.
Indian Head, Sask	7	Apr. 17	Apr. 7, 1906.
South Qu'Appelle, Sask	12	Apr. 16	Apr. 6, 1903.
Tombstone, Ariz			Feb. 13, 1910.
Southern Colorado	3	Mar. 16	Feb. 13, 1908.
Fort Shaw, Mont			Feb. 28, 1868.
Big Sandy, Mont			Apr. 6, 1905.
Lawen, Oreg			Apr. 1, 1909.

Resident sandhill cranes of Cuba and Florida nest much earlier than the migrants from farther north. In Cuba eggs are most common in March, but some are laid earlier, for specimens in the U. S. National Museum were taken at Lantana, Fla., February 6–23, 1894, and at Manatee, Fla., March 2, 1873. The earliest eggs at Jackson, Mich., were collected May 8, 1901, and May 5, 1902 (Arnold); Summerfield Township, Monroe County, Mich., May 2, 1880 (Arnold); Dubuque, Iowa, May 11, 1865 (specimens in U. S. National Museum); Hayfield, Iowa, about May 17, 1894 (Anderson); Delavan, Wis., May 30, 1883 (Kumlien and Hollister); Minnewaukan, N. Dak., May 2, 1898 (Rolfe); Camp Harney, Oreg., May 2, 1875, April 27, 1876, April 24, 1877, and April 14, 1878 (Bendire); Gunnison County, Colo., at 8,000 feet altitude, June 5, 1903 (Warren); and Big Quill Lake, Sask., June 20, 1909 (Barnes).

Fall migration.

Place.	Number of years' records.	Average date of fall arrival.	Earliest date of fall arrival.
Waverly, Mo			Oct. 10, 1890
Grape Vine, Tex	10	Oct. 13	Oct. 3, 1893
Onaga, Kans	5	Oct. 22	Oct. 12, 1898
Southeastern South Dakota	5	Sept. 17	Sept. 8, 1891
Beloit, Colo			Sept. 24, 1890

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Aweme, Man	7	Oct. 15	Oct. 31, 1900
Heron Lake, Minn			Nov. 9, 1885
Delavan, Wis			Oct. 23, 1892
Grinnell, Iowa	4	Oct. 16	Oct. 22, 1887
Bicknell, Ind			Oct. 27, 1894
Manchester, Mich			Nov. 24, 1896
Terry, Mont			Nov. 10, 1903
Southeastern South Dakota	4	Nov. 1	Nov. 7, 1889
Wet Mountains, Colo			Nov. 15, 1899
Eastern Nebraska	6	Oct. 25	Nov. 3, 1891
Richmond, Kans			Nov. 3, 1885
Caddo, Okla			Nov. 11, 1883
Bonham, Tex			Nov. 9, 1889

LIMPKIN. *Aramus vociferus* (Latham).

Range.—Southeastern United States, the Greater Antilles, and Central America.

The limpkin is a nonmigratory bird whose range extends from northwestern Costa Rica—Rio Frio (Richmond), Bebedero, La Palma, and Bolson (Carriker)—through western Nicaragua (Ometepe Island) and western Honduras (Ceiba) to Tehuantepec City, Oaxaca (Nelson and Goldman), and Alvarado, Vera Cruz (Sumichrast). It occurs in the Greater Antilles, but is rare in Porto Rico (Gundlach) and still rarer (if not now extinct) in Jamaica (Field). It was noted January 28, 1901, at Cay Lobos Light, Bahamas, near the northern coast of Cuba.

The species was formerly very abundant on the interior waters of Florida, and, though greatly reduced in numbers, it still occurs over most of its former range, which extended north to Waukeenah (Wayne) and Palatka (Hasbrouck). A few wander in winter to Indian Key, Key West, and the Tortugas (specimens in the U. S. National Museum), and have occurred casually at Twiggs Dead River, Aiken County, S. C., October 18, 1890 (Wayne); Charleston, S. C., July, 1904 (Wayne); and Brownsville, Tex., May 29, 1889 (Sennett).

The nesting season extends over nearly half the year, eggs having been found in Cuba during December and January (Gundlach), and on the Oklawaha River, Fla., from the middle of February to June 20 (Jackson).

KING RAIL. *Rallus elegans* Audubon.

Range.—Eastern United States and Cuba

Breeding range.—The king rail is the large fresh-water rail of eastern United States, in contrast with the clapper rail, which is confined to salt marshes. The king rail breeds in Florida and north along the Atlantic coast to Saybrook, Conn. (Clark). While for the most part keeping in the marshes near the coast, it has been known to nest as far inland as Raleigh, N. C. (Brimley), and Columbia, S. C. (Taylor). In the Mississippi Valley and the region of the Great

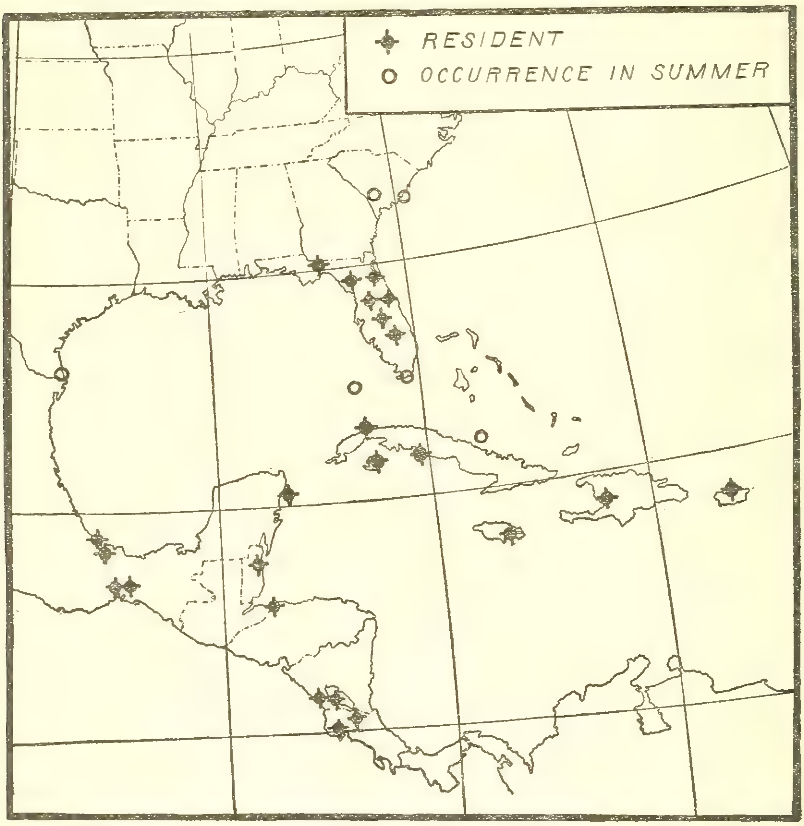

FIG. 4.—Limpkin (*Aramus vociferus*).

Lakes, it nests north to Ithaca, N. Y. (Wright and Allen), Buffalo, N. Y. (Reinecke), Pelee Island, Ohio (Jones), St. Clair Flats, Ont. (Swales), Ann Arbor, Mich. (Covert), Madison, Wis. (Slonaker), and Faribault, Minn. (Bullis). The breeding range extends west to Heron Lake, Minn. (Miller), Omaha, Nebr. (Bruner, Wolcott, and Swenk), Manhattan, Kans. (Lantz), and Wichita, Kans. (Matthews). The southern limit of normal breeding extends south to Wooster, Ohio (Oberholser), Circleville, Ohio (Bales), Greencastle, Ind. (Earle), Odin, Ill. (Vandercook), and Boonville, Mo. (Hoy). A few pairs breed south to Portageville, Mo. (Howell), and Eureka Springs, Ark. (Smith). The species has been reported to breed at Orange Lake,

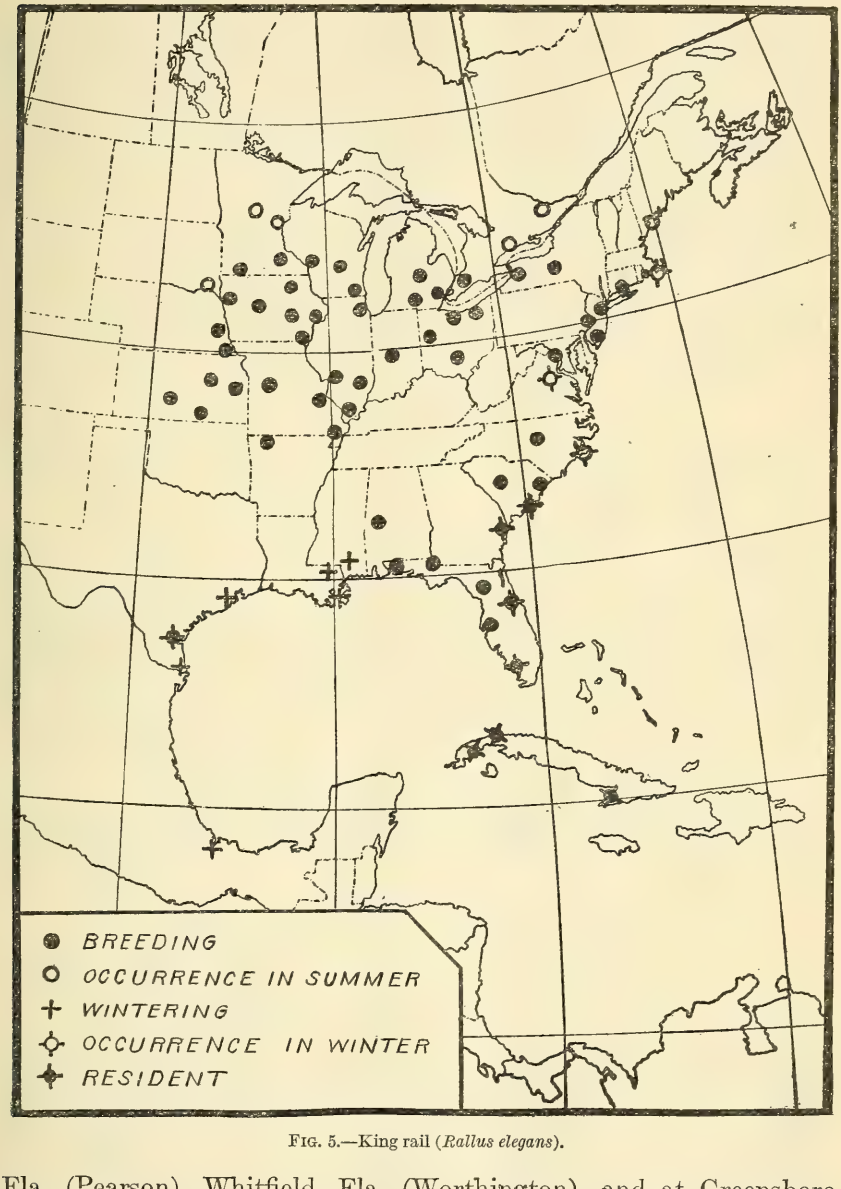

FIG. 5.—King rail (*Rallus elegans*).

Fla. (Pearson), Whitfield, Fla. (Worthington), and at Greensboro, Ala. (Avery), while an individual too young to have been hatched at any great distance away was taken at Corpus Christi, Tex., July 14, 1910 (Thayer).

Following are a few records of stragglers beyond the breeding area: Ottawa, Ont., May 7, 1896 (White); Ottertail County, Minn. (Roberts); Falmouth, Me., September 19, 1895 (Brock); Scarborough, Me., October 8, 1881 (Brown); and Vermilion, S. Dak. (Agersborg).

Winter range.—It can be said in general that the king rail winters in the southern part of the breeding range, and also in southern Louisiana (Beyer) and on the coast of Texas at least as far south as Brownsville (Thayer). There is one record of its occurrence in Mexico, probably as a straggler, at Tlacotalpam, Vera Cruz, January 18, 1901 (Colburn).

A remarkable fact in the life history of the king rail is its moving northward on the Atlantic coast after the breeding season and then attempting to winter there. Only a small percentage of the birds perform this northward migration, but there are many records north of their normal winter home in the marshes of South Carolina during the winter: Currituck Sound, N. C., December 14, 1909 (McAtee); Raleigh, N. C., January 23, 1892 (Brimley); Washington, D. C., December 12, 1908, December 16, 1889, December 21, 1892, January 19, 1901, and February 8, 1887; Stafford, Md., January 28, 1893 (Kirkwood); Milford, Conn., December 15, 1892 (Verrill); Saybrook, Conn., January 14, 1876 (Clark); Newport, R. I., January 21, 1896 (Howe and Sturtevant); Cambridge, Mass., December 30, 1896 (Farley); Ellisville, Mass., January 20, 1903 (Reagh); Chatham, Mass., December 28, 1908 (Fay); West Barnstable, Mass., December 30 or 31, 1909 (Howe); and Portland, Me., December 17, 1899 (Brook). A few far-northern winter records have been reported from the interior: Beaver Dam, Wis., December 19, 1906 (Snyder); near Port Huron, Mich., December 13, 1902 (Eppinger); Hudson, Mich., December 11, 1896 (Boies); Point Pelee, Ont., December 31, 1906 (Taverner and Swales); and South Buffalo, N. Y., December 3, 1897 (Savage).

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Raleigh, N. C	4	Mar. 26	Feb. 8, 1887
Montauk, N. Y			Mar. 3, 1887
Peabody, Mass			Mar. 13, 1908
Erie, Pa			Apr. 17, 1902
Fayette, Mo			Apr. 2, 1887
Chicago, Ill	14	Apr. 21	Apr. 10, 1887
Rockford, Ill			Apr. 3, 1887
Terre Haute, Ind	2	Apr. 26	Apr. 24, 1888
New Bremen, Ohio			Apr. 19, 1909
Oberlin, Ohio	5	May 7	May 4, 1908
Point Pelee, Ont			Apr. 22, 1908
Petersburg, Mich			Apr. 20, 1886
Keokuk, Iowa	5	Apr. 22	Apr. 10, 1894
Grinnell, Iowa			Apr. 5, 1889
Heron Lake, Minn	2	May 7	Apr. 22, 1890
Emporia, Kans			Apr. 14, 1885
Onaga, Kans			Apr. 23, 1891
Falls City, Nebr			Apr. 13, 1889

Young out of nest of the king rail were found at Mount Pleasant, S. C., March 22, 1913 (Wayne); eggs ready to be laid, at Greensboro, Ala., March 24, 1884 (Avery); eggs at Frogmore, S. C., March 22, 1884 (Hoxie); Raleigh, N. C., May 28, 1890 (Brimley); Washington, D. C., May 30, 1910 (Dickey); Tolchester, Md., May 30, 1891 (Fisher); Tinicum, Pa., June 2, 1907 (Carter); near Philadelphia, Pa., June 3, 1902 (Miller); Buffalo, N. Y., May 30, 1894 (Reinecke); Lyme, Conn., June 13, 1884 (Clark); Chicago, Ill., May 11, 1902–June 19, 1902 (Abbott); Aledo, Ill., May 12, 1880 (specimens in U. S. National Museum); Quiver Lake, Ill., May 18, 1895 (Silloway); Kewanee, Ill., May 22, 1893, and once as early as April 29, 1894 (Murchison); Circleville, Ohio, May 14, 1910 (Bales); Fays Lake, Mich., May 30, 1894 (Watkins); Iowa City, Iowa, May 29, 1884 (Clute); Manhattan, Kans., May 28, 1883 (Lantz); Lincoln, Nebr., May 30, 1910 (Zimmer); and Shawneetown, Ill., young out of nest, June 17, 1909 (Howell).

Fall migration.

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Bayport, N. Y.			Nov. 2, 1886
Ithaca, N. Y.			Nov. 29, 1901
Chicago, Ill.	6	Sept. 14	Sept. 30, 1907
Canton, Ill.			Oct. 27, 1894
Cedar Point, Ohio			Oct. 22, 1906
Keokuk, Iowa	3	Sept. 20	Sept. 26, 1899
Delavan, Wis.			Oct. 22, 1894
Lincoln, Nebr.			Sept. 22, 1900
Lawrence, Kans.			Nov. 4, 1905
Caddo, Okla.			Nov. 1, 1883

[**CUBAN KING RAIL.** *Rallus elegans ramsdeni* Riley.

The king rails of Cuba have recently been segregated under the name *ramsdeni*. The species is resident on the island and is fairly common. It is said to nest in June and July (Gundlach).]

[**MEXICAN KING RAIL.** *Rallus tenuirostris* Ridgway.

The Mexican representative, *tenuirostris*, of the common king rail (*elegans*) occurs in central Mexico from the Laguna del Rosario, Tlaxcala (Ferrari-Perez), to the Valley of Mexico (White), and Mazatlan (Lawrence). The species was found fairly common at Lerma during early July, 1904 (Nelson and Goldman), and eggs were taken the first day of that month.]

BELDING RAIL. *Rallus beldingi* Ridgway.

The Belding rail is a resident species in the Cape region of Lower California from Magdalena Bay southward. Eggs were taken at San Jose Island, Lower California, June 28, 1908 (Thayer).

CALIFORNIA CLAPPER RAIL. *Rallus obsoletus* Ridgway.

The California clapper rail has a very restricted range. It remains throughout the year in the salt marshes near the mouth of the Sacramento River, from Petaluma (Newberry) on the north to Palo Alto (McGregor) on the south. The species was very abundant in these marshes until about 1890, but it has decreased decidedly in numbers and is now rather rare, though several specimens were obtained October 18–30, 1909, at Redwood (Thayer). Eggs have been taken at Haywards, April 18, 1885 (Emerson); at San Mateo, April 24, 1879 (Bryant); and at Palo Alto, May 1, 1899 (Thayer).

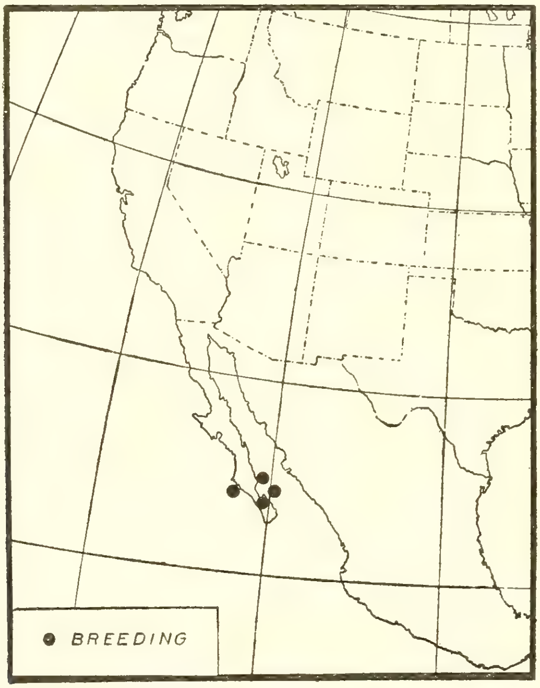

FIG. 6.—Belding rail (*Rallus beldingi*).

LIGHT-FOOTED RAIL. *Rallus levipes* Bangs.

The light-footed rail is a nonmigratory species occurring along the Pacific coast from Santa Barbara, Cal. (Henshaw), south to San Quintin Bay, Lower California. It is most common on the coast of Los Angeles and San Diego Counties. A specimen was taken August 25, 1902, at Yuma, Ariz. (Brown).

Eggs have been secured at Ballona, Cal., May 16, 1894 (Judson); Nigger Slough, Los Angeles County, Cal., May 29, 1906 (Willett); San Diego, Cal., April 16, 1895, and April 8–10, 1900 (Thayer); and at San Quintin Bay, Lower California, April 27, 1910 (Howell).

CLAPPER RAIL. *Rallus crepitans crepitans* Gmelin.

Range.—The clapper rail and its various subspecies inhabit salt-water marshes of the eastern United States from New England to Texas, and the Bahama Islands.

The species has been separated into five subspecific forms, the most northern of which, *crepitans*, the type, breeds from New Haven, Conn. (Bishop), south along the coast to Cobb Island, Va. (Fisher), though it is not common north of New Jersey. So abundant were these rails formerly on this coast that in September, 1896, near Atlantic City, about 10,000 were killed in two days. The species occurred once inland to Washington, D. C., September 18,

FIG. 7.—California clapper rail (*Rallus obsoletus*).

1882 (Coues); and has been noted at East Orleans, Mass., November 30, 1895 (Brewster); Plum Island, Mass., September 15, 1908 (Wharton); Boston Harbor, Mass., May 4, 1875 (Purdie); Kingston, Mass., December 29, 1885 (Browne); Sabattus Pond, Me., 1874 (Smith); and Popham Beach, Me., October 12, 1900 (Knight).

A few remain in winter as far north as Five Mile Beach, N. J. (Laurent), and occasionally on Long Island, N. Y. (Lawrence). They are abundant in winter on the coast of North Carolina, common in South Carolina, and range south to St. Marys, Ga. (Oberholser).

Eggs have been taken near Cobb Island, Va., from May 19, 1894, to July 17, 1884 (specimens in U. S. National Museum); Stone Harbor, N. J., May 28, 1907 (Carter), to July 7, 1903 (Miller); and South Oyster Bay, N. Y., May 24, 1884 (specimens in U. S. National Museum).

Birds that winter in Georgia sometimes remain there until after the local breeding birds have eggs, since specimens of *crepitans* were taken April 4, 1896, at St. Marys, Ga., while eggs of *waynei* have been found in Georgia in March.

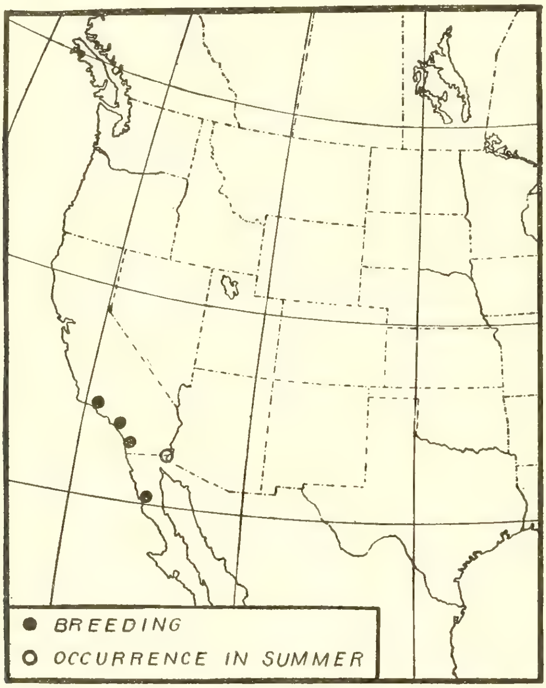

FIG. 8.—Light-footed rail (*Rallus levipes*).

LOUISIANA CLAPPER RAIL. *Rallus crepitans saturatus* Ridgway.

The Louisiana clapper rail is common and resident in the salt marshes of that State and ranges east to Perdido Bay, Ala. (Howell), and west to Corpus Christi, Tex. (Sennett).

Under this form are now included all the specimens from Texas that were formerly identified as *Rallus longirostris caribaeus*. Eggs have been taken near Corpus Christi, Tex., as late as July 23–27, 1910 (Thayer).

FLORIDA CLAPPER RAIL. *Rallus crepitans scotti* Sennett.

The Florida clapper rail is confined to Florida and is a resident of the western coast from Charlotte Harbor north to the mouth of the Suwanee River. Downy young have been found from early May to early July (Scott); and eggs, March 31, 1897, near the mouth of the Anclote River (Bishop).

WAYNE CLAPPER RAIL. *Rallus crepitans waynei* Brewster.

The Wayne clapper rail is the common rail of the salt-water marshes on the coast of South Carolina and Georgia and breeds south

FIG. 9.—Clapper rail (*Rallus crepitans*). Subspecies: 1, *crepitans;* 2, *waynei;* 3, *scotti;* 4, *saturatus;* 5, *coryi.*

to Matanzas Inlet, Fla. (eggs in the U. S. National Museum), and north to Pea Island, N. C. (Bishop). It ranges in winter a short distance south of the breeding grounds to Dummits Creek, Fla. (Brewster), while a few remain through this season at the northern limit of the range on the coast of North Carolina (Bishop).

Eggs have been taken near Matanzas Inlet, Fla., May 28, 1895 (specimens in U. S. National Museum); McIntosh, Ga., March 29, April 16, and May 6, 1890 (specimens in U. S. National Museum); Mount Pleasant, S. C., April 10, 1903 (Wayne); Frogmore, S. C., June 9, 1886 (Hoxie); Fort Macon, N. C., May 9, 1869 (Coues); and Pea Island, N. C., May 20, 1901 (Bishop). They have been obtained at Amelia Island, Fla., as late as July 25, 1906 (Thayer).

[**BAHAMA CLAPPER RAIL.** *Rallus crepitans coryi* Maynard.

The Bahama clapper rail is quite common throughout most of the Bahamas, where it is resident.]

[**CARIBBEAN CLAPPER RAIL.** *Rallus longirostris caribaeus* Ridgway.

The Caribbean clapper rail is confined to the West Indies, occurring on most of the Lesser Antilles, the Bahamas, and Jamaica.

The form which occurs and is resident on Cuba has been separated under the name *Rallus longirostris cubanus* Chapman. The type species, *longirostris*, is confined to South America, ranging from Guiana to Peru.]

[**YUCATAN CLAPPER RAIL.** *Rallus pallidus* Nelson.

The type and only known specimen of the Yucatan clapper rail was taken April 15, 1893, on the Rio Lagartos, Yucatan.]

VIRGINIA RAIL. *Rallus virginianus* Linnaeus.

Range.—North America, from southern Canada to Florida and Guatemala.

Breeding range.—The Virginia rail is a common breeding bird in suitable localities throughout northern United States and north to Kentville, N. S., (Bishop), Scotch Lake, N. B. (Moore), Quebec City, Canada (Dionne), Ottawa, Ont. (White), Port Sydney, Ont. (Fleming), Kelly Brook, Wis. (Schoenebeck), Mille Lacs, Minn. (Trippe), Winnipeg, Man. (Hine), Chemawawin, Keewatin (Nutting), Little Manito Lake, Sask. (Atkinson), Columbia Falls, Mont. (Williams), 158-Mile House, B. C. (Brooks), and Goldstream, Vancouver Island, B. C. (Streeter). It has occurred casually north to Newfoundland (Reeks), Hamilton Inlet, Que. (Turner), York Factory, Keewatin (Bell), near Edmonton, Alta. (Stansell), and Campbell River, at the northern end of Vancouver Island, B. C. (Brooks).

Southward the breeding range extends to Cape May, N. J. (Stone), State College, Pa. (Harlow), Dubois, Pa. (Van Fleet), Lewiston Reservoir, Ohio (Fisher), Henderson, Ky. (Audubon), Lincoln, Nebr. (Coleman), San Luis Lakes, Colo. (Aiken), Salt Lake, Utah (Ridgway), and Escondido, Cal. (Sharp). A specimen which may have been breeding was taken May 18, 1886, at Pecks Lake, Ariz. (Mearns). The species once nested in Pamlico Sound, N. C. (Pearson), and strangely enough it was found nesting in 1904 at Lerma, Mexico (Goldman), more than 1,000 miles from the nearest previously known breeding grounds. It was also found in June at Tizimin in northern Yucatan (Sharpe), and may have been breeding.

Winter range.—The Virginia rail winters for the most part in the southern United States, occurring on the Gulf coast from Fort Myers, Fla. (Scott), to Corpus Christi, Tex. (Sennett), and south to Duenas, Guatemala—January, 1861—(Salvin), and San Jose del Cabo, Lower California (Brewster). It was found once—January, 1854—in the market of Habana, Cuba (Gundlach), and once—November 6, 1851—

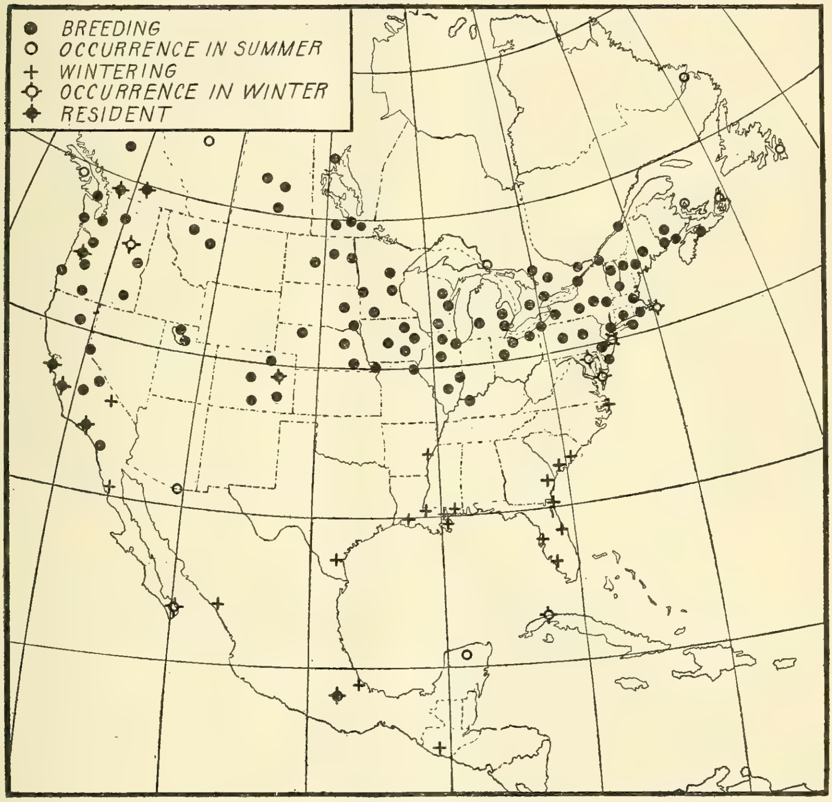

FIG. 10.—Virginia rail (*Rallus virginianus*).

in the Bermudas (Hurdis). The species winters regularly and commonly on the coast of South Carolina (Wayne), less commonly or rarely north to Pea Island, N. C. (Bishop). It has been found casually in winter near Washington, D. C., December 28, 1912 (Adams); at Easton, Md., Jaunary 20, 1891 (Kirkwood); Cape May, N. J., December 30, 1895 (Stone); Trenton, N. J., January, 1869 (Abbott); Worcester, Mass., January 1, 1891 (Reed); and Barnstable, Mass., December 31, 1894 (Hoffmann). In the Mississippi Valley it remains as far north during the winter as Arkansas County, Ark. (Hollister), and on the Pacific coast almost to the northern limit of its breeding range at Chilliwack, B. C. (Brooks), and Okanogan, B. C. (Brooks). There is an isolated winter colony at Barr Lake, Colo. (Hersey and Rockwell); one wintered at Colorado Springs in 1898–99 (Aiken); one at Boulder in 1909–10 (Betts); three at Helena, Mont., 1910–11 (Saunders); and several near Provo, Utah, 1911–12 (Goodwin). One was taken January 16, 1879, at Walla Walla, Wash. (Baird, Brewer, and Ridgway).

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Raleigh, N. C	3	Apr. 10	Apr. 7, 1900
Washington, D. C			Apr. 6, 1892
Baltimore, Md			Mar. 20, 1895
Erie, Pa			Apr. 18, 1900
Branchport, N. Y. (near)	10	Apr. 26	Apr. 7, 1905
Ithaca, N. Y			Apr. 24, 1904
Eastern Massachusetts	6	Apr. 25	Apr. 14, 1899
St. Louis, Mo			Mar. 31, 1887
Bowling Green, Ky			Apr. 6, 1902
Central Indiana	5	Apr. 20	Apr. 17, 1892
Chicago, Ill	10	Apr. 28	Apr. 16, 1907
Southern Wisconsin	9	Apr. 25	Apr. 19, 1896
Southwestern Ontario	5	Apr. 27	Apr. 23, 1889
Oberlin, Ohio	10	May 2	Apr. 15, 1907
Vicksburg, Mich	4	May 4	Apr. 27, 1904
Lincoln, Nebr			Apr. 28, 1900
Springfield, S. Dak			May 13, 1910
Grand Forks, N. Dak			May 14, 1903
Aweme, Man	2	May 16	May 10, 1896
Indian Head, Sask	3	May 23	May 19, 1910
Tucson, Ariz			Apr. 11, 1886
Fort Custer, Mont			May 11, 1885
Columbia Falls, Mont			May 16, 1894
Stony Plain, Alta			May 20, 1908

The latest dates of the Virginia rail in its winter home are: Savannah, Ga., April 3, 1908 (Hoxie); Charleston, S. C., April 5 (Wayne); Bayou Sara, La., April 15, 1882 (Beckham); and Bay St. Louis, Miss., April 19, 1902 (Allison).

Eggs have been found at Erie, Pa., May 26, 1891, and June 2, 1892 (Todd); Ithaca, N. Y., May 18, 1905 (Reed and Wright); Portland, Conn., May 23, 1894 (Sage); Framingham, Mass., May 17, 1890 (Coombs); Hampton, N. H., May 28, 1887 (Shaw); Elkhart County, Ind., May 19, 1890 (McBride); Oberlin, Ohio, May 8, 1903 (Jones); Detroit, Mich., May 25, 1891 (Swales); Iowa City, Iowa, May 29, 1884 (Clute); Cedar Rapids, Iowa, May 8, 1902 (Hathorn); Pewaukee, Wis., May 23, 1871 (specimens in U. S. National Museum); Boulder, Colo., May 28, 1904 (Henderson); Barr Lake, Colo., May 18, 1907–July 6 (Rockwell); Fort Crook, Cal., May 13, 1861 (specimens in U. S. National Museum); Walla Walla, Wash., April 26, 1882 (specimens in U. S. National Museum); and Tacoma, Wash., March 30, 1908 (Bowles). Eggs have been noted as late as July 19, 1903, at Odessa, Del. (Pennock), and young in the nest August 5, 1896, at Hartland, Me. (Knight).

Fall migration.

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Scotch Lake, N. B.			Sept. 23, 1900
Montreal, Canada			Oct. 23, 1897
Marlow, N. H.			Oct. 1, 1881
Eastern Massachusetts	4	Sept. 22	Nov. 9, 1898
Hartford, Conn.	3	Oct. 3	Oct. 9, 1895
Renovo, Pa.	3	Sept. 28	Oct. 2, 1895
Erie, Pa.			Oct. 28, 1893
Montauk, N. Y.			Oct. 30, 1900
Ottawa, Ont.	4	Oct. 6	Oct. 28, 1897
Circleville, Ohio			Nov. 23, 1880
Delavan, Wis.	2	Oct. 15	Oct. 16, 1894
Vicksburg, Mich.	4	Nov. 9	Nov. 17, 1903
Margaret, Man.	2	Sept. 20	Sept. 21, 1911
White Earth, Minn.			Sept. 15, 1880
Lake Andrew, Minn.			Oct. 5, 1891
Fort Snelling, Minn.			Nov. 11, 1890
Provo, Utah			Nov. 27, 1872
St. George, Utah			Nov. 3, 1909

The Virginia rail usually returns to southern Mississippi about September 15, earliest September 3, 1902; Washington, D. C., September 4, 1911; Raleigh, N. C., September 8, 1896; and South Carolina the last of September.

[SPOTTED RAIL. *Linnopardalus maculatus* (Boddaert).

The eastern coast of South America is included in the range of the spotted rail, from Paraguay and Argentina to Guiana, and to Colombia, with the islands of Trinidad and Tobago. The species reappears in Cuba, but there seems to be a long break in the range from Cuba to Colombia.]

[LAWRENCE WOOD RAIL. *Aramides axillaris* Lawrence.

The Lawrence wood rail is a species of wide distribution, ranging north on the Pacific side of Mexico to Mazatlan (Grayson), and quite common at San Blas, Tepic, June 12, 1897 (Nelson and Goldman); while on the Atlantic slope it was noted at Las Bocas de Silan (Cabot), and Mujeres Island, March 24, 1901 (Nelson and Goldman), both in northern Yucatan. It has also been taken at Acapulco, Guerrero, January 14, 1895 (Nelson and Goldman), and Belize (Bocourt). It seems to be very rare between southern Mexico and northern South America, though it has been found at Carrillo and Lepanto, Costa Rica (Carriker). It occurs on the northern coast of South America from Barranquilla, Colombia, to Venezuela, Trinidad Island, and British Guiana.]

[CAYENNE WOOD RAIL. *Aramides cajanea* (Müller).

The Cayenne wood rail ranges from eastern and central Brazil to Peru and north to British Guiana and Colombia. It is a common species in Panama and extends along both coasts to northern Costa Rica.]

[MANGROVE WOOD RAIL. *Aramides albiventris* Lawrence.

The Mangrove wood rail has a wide distribution on the eastern side of Mexico north to Alta Mira and is abundant in favorable localities along the coast of Vera Cruz and east to Cozumel Island, Yucatan; Belize; and Omoa and San Pedro, Honduras. It is also common on the Pacific side from the coast of Guatemala west to Huilotepec and Guichicovi, Oaxaca.]

[**NICARAGUA WOOD RAIL.** *Aramides plumbeicollis* Zeledon.

The range of the Nicaragua wood rail is along the coast of Nicaragua and north to the Segovia River, eastern Honduras, and south in northeastern Costa Rica to the foothills of the Volcano Turrialba.]

[**RED RAIL.** *Amaurolimnas concolor* (Gosse).

Little is known of the distribution of the red rail. It was originally described from Jamaica and has since been recorded from Guatemala, Honduras, Nicaragua, Guiana, and Brazil.]

SPOTTED CRAKE. *Porzana porzana* (Linnaeus).

Several specimens of the spotted crake have been taken in the fall on the western coast of Greenland at Godthaab, Nanortalik, and Julianehaab. All were wanderers beyond the normal range of the species, which includes nearly all of Europe north to latitude 65° and east in Asia to Yarkand, Turkestan. The species winters in southern Asia and in Africa.

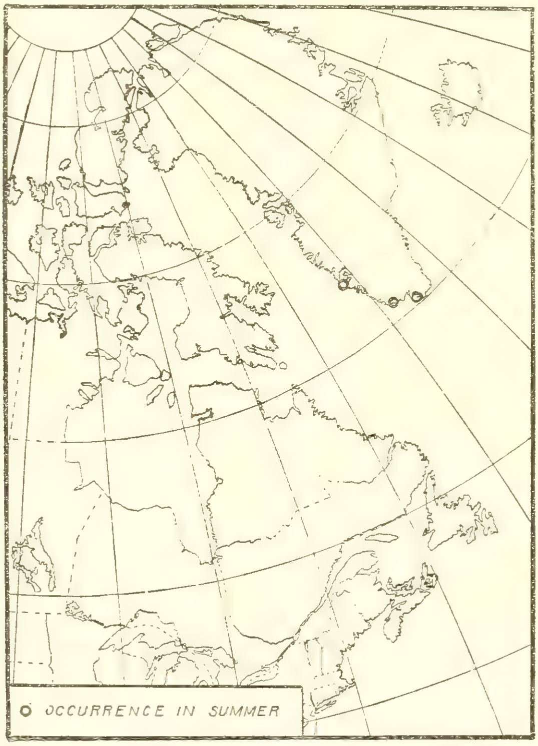

FIG. 11.—Spotted crake (*Porzana porzana*).

SORA. *Porzana carolina* (Linnaeus).

Range.—North America, north to central British Columbia, southern Mackenzie, and the Gulf of St. Lawrence; thence south through the West Indies and Central America to Venezuela and Peru.

Breeding range.—The sora, or, as it is often called, the Carolina rail, breeds throughout northern United States and north to Grand Manan Island, N. B. (Osgood), Prince Edward Island (Bagster), Godbout, Que. (Comeau), Moose Factory, Ont. (Spreadborough), Fort Churchill, Keewatin (Clarke), Fort Rae, Mackenzie (Baird, Brewer, and Ridgway), Fort Simpson, Mackenzie (Preble), Cariboo District, B. C. (Brooks), and Victoria, B. C. (Rhoads). The species has also been noted as a wanderer north to Nova Scotia (Willis), Newfoundland (Reeks), Harrington, Que., July, 1907 (Townsend), Sandwich Bay,

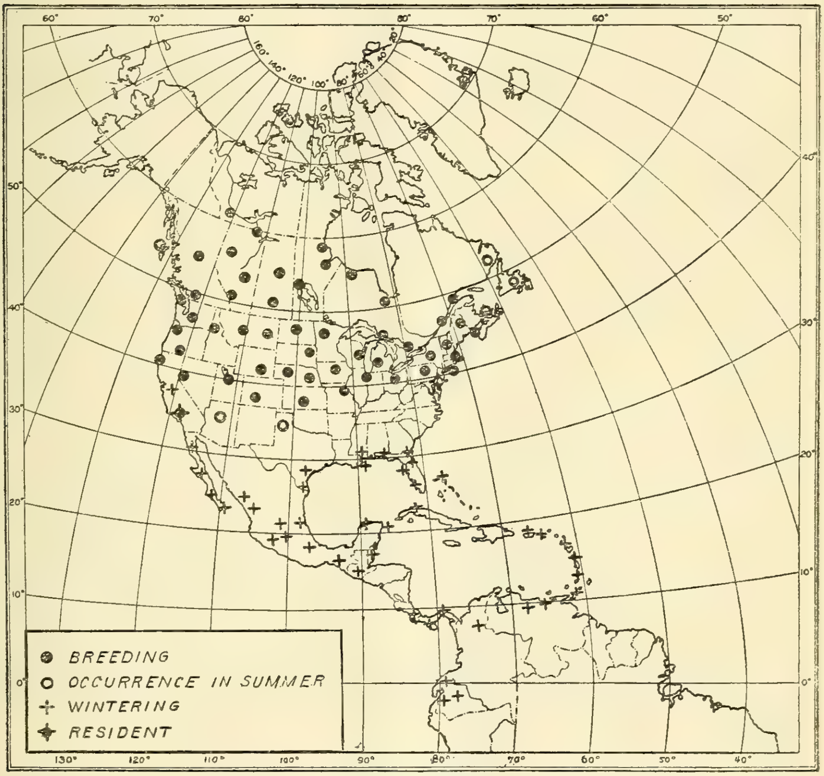

FIG. 12.—Sora, or Carolina rail (*Porzana carolina*).

Que., 1898 (Townsend and Allen), Massett, B. C. (Keen), and Sukkertoppen, Greenland, October 3, 1823 (Reinhardt); several other specimens are reported from the west coast of Greenland, the most northern of which is from Umanak, latitude 70° (Schalow).

The breeding range extends south to Philadelphia, Pa. (Audubon), Warren, Ohio (Dana), Lewiston Reservoir, Ohio (Fisher), Philo, Ill. (Hess), Independence, Mo. (Widmann), Osawatomie, Kans. (Colvin), near Breckenridge, Colo. (Carter), Utah Lake, Utah (Johnson), Pyramid Lake, Nev. (Ridgway), and Escondido, Cal. (Hatch).

Winter range.—The flight of the sora is slow and labored (see p. 4), but some individuals travel more miles between the summer and winter homes than almost any other rails in the Western Hemisphere. The birds breeding in the Mackenzie Valley do not winter farther north than the Gulf coast and hence must travel at least 2,500 miles during their fall migration. The species passes in winter to about latitude 5° S., and as none of these South American birds nest south of latitude 35° N. the migration route can not possibly be shorter than 3,000 miles and may be much longer.

The sora is dispersed in winter throughout the Greater and the Lesser Antilles and must take long flights over water in passing from one island to another. Moreover, the species is common in winter in northern Yucatan, and these individuals undoubtedly fly back and forth over the Gulf of Mexico, making a distance of at least 500 miles in a single flight.

The sora winters in Mexico, Central America, the West Indies, and northwestern South America, south to Tumbez, Peru (Taczanowski), and east to Medellin, Colombia (Sclater and Salvin), Lake Valencia, Venezuela (Sclater and Salvin), Caracas, Venezuela (Ernst), and to the island of Trinidad (Sharpe), and Tobago Island (Jardine). It also winters in the northern Bahamas (Bonhote), Bermuda (Hurdis), and in Florida north to Amelia Island (Worthington) and Whitfield (Worthington). It is rather common in winter along the coasts of Mississippi, Louisiana, and Texas, in Lower California, and in western California north to Marysville (Belding).

Stragglers have been seen in winter far north of the regular range at this season, at Canton, Md., December 26, 1890, and January 22, 1895 (Kirkwood); Rochester, N. Y., December 12, 1882 (Coues); Seaford, N. Y., December 24, 1908 (Braislin); Hartford, Conn., December 29, 1881; Salem, Mass., about December 22, 1874 (Newcomb); Rantoul, Ill., December 27, 1910 (Ekblaw); Lanesboro, Minn., January 25, 1894 (Hvoslef); and Pecks Lake, Ariz., January 24, 1887 (Mearns).

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Cumberland, Md			Mar. 7, 1902
Kirkwood, Ga			Mar. 31, 1896
Otranto, S. C			Feb. 3, 1909
Mount Pleasant, S. C			Mar. 4, 1895
Raleigh, N. C	5	Apr. 19	Apr. 6, 1886
Erie, Pa	3	May 4	Mar. 31, 1902
Lockport, N. Y. (near)	8	Apr. 30	Apr. 22, 1890
Hartford, Conn			Apr. 18, 1888
Quonochontaug, R. I			Mar. 2, 1900
Cambridge, Mass			Apr. 23, 1897
Pittsfield, Me	3	May 16	May 14, 1899
Quebec City, Canada			May 27, 1892

Spring migration—Continued.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Petitcodiac, N. B			May 17, 1888
Bowling Green, Ky	2	Apr. 16	Apr. 5, 1902
Kansas City, Mo	2	Apr. 18	Apr. 17, 1902
Chicago, Ill	11	Apr. 19	Apr. 11, 1896
New Bremen, Ohio			Apr. 19, 1909
Oberlin, Ohio	11	May 2	Apr. 22, 1907
Ann Arbor, Mich	6	May 3	Apr. 13, 1908
Vicksburg, Mich	6	Apr. 19	Apr. 11, 1904
Toronto, Ont	3	May 6	Apr. 23, 1891
Ottawa, Ont	6	May 11	May 8, 1910
Sioux City, Iowa			Apr. 20, 1902
Keokuk, Iowa	6	Apr. 21	Apr. 16, 1893
Madison, Wis	6	May 2	Apr. 19, 1908
La Crosse, Wis	6	May 3	Apr. 20, 1906
Heron Lake, Minn	5	May 5	Apr. 21, 1889
Minneapolis, Minn	9	May 1	Apr. 25, 1889
White Earth, Minn	2	May 6	May 4, 1882
Gainesville, Tex			Apr. 8, 1885
Onaga, Kans	3	May 5	Apr. 29, 1893
Badger, Nebr	4	May 10	May 7, 1886
Northern North Dakota	5	May 14	May 3, 1908
Aweme, Man	8	do	Apr. 30, 1902
Indian Head, Sask	5	May 17	May 12, 1906
Fort Simpson, Mackenzie			May 19, 1904
Tucson, Ariz			Apr. 18, 1886
Boulder, Colo			May 8, 1910
Jackson, Wyo			Apr. 26, 1911
Terry, Mont			May 9, 1906
Edmonton, Alta	2	May 11	May 10, 1903
Grapevine Spring, Cal			Apr. 1, 1891
Fort Klamath, Oreg			Mar. 28, 1887
Chilliwack, B. C	2	Apr. 11	Apr. 9, 1889
Okanogan Landing, B. C			Apr. 26, 1906

The sora has been found at Swan Island, Honduras, as late as March 25, 1887 (Ridgway); Lake Amatitlan, Guatemala, March 9, 1906 (Dearborn); Isla de los Pajaros, Vera Cruz, April 20, 1904 (Sheldon); Alta Mira, Tamaulipas, April 12, 1898 (Goldman); St. Croix Island, West Indies, April 24, 1858 (Newton); Bermuda, April 26, 1849 (Jardine); Sombrero Key Lighthouse, Fla., April 19, 1887 (Marshall); Whitfield, Fla., May 7, 1903 (Worthington); Cumberland, Ga., April 15, 1902 (Helme); Charleston, S. C., May 14, 1910 (Chamberlain); Kirkwood, Ga., May 12, 1897 (Smith); Raleigh, N. C., average May 13, latest May 18, 1888 (Brimley); Cumberland, Md., May 30, 1901 (Eifrig); Hester, La., April 23, 1902 (Pring); Bay St. Louis, Miss., April 20, 1902 (Allison); Bellevue, Tenn., May 20, 1895 (Rhoads); and Hidalgo, Tex., May 20, 1889 (Sennett).

Eggs of the sora were secured at Erie, Pa., May 25, 1892 (Todd); State College, Pa., June 7, 1909 (Harlow); Mount Holly, N. J., June 2, 1871 (specimens in U. S. National Museum); Stamford, Conn., May 12, 1897 (Howes); Ponkapog, Mass., May 29, 1895 (Bowles); Montreal, Canada, June 8, 1889 (Wintle); Waterloo, Ind., May 16, 1890 (McBride); Plymouth, Mich., May 19, 1889 (Purdy); Bay City, Mich., May 25, 1892 (Eddy); Ottawa, Ont., June 18, 1900 (Dawson); Forest, Iowa, May 30, 1893 (Anderson); Horicon, Wis., May 26, 1882

(Goss); Pitrodie, S. Dak., June 1, 1888 (Cheney); Reaburn, Man., June 4, 1893 (Dippie); Long Lake, Man., June 7, 1894 (Arnold); Crane Lake, Sask., June 9, 1894 (Macoun); Big Quill Lake, Sask., June 12, 1909 (Ferry); Terry, Mont., June 18, 1898 (Cameron); Lake Valley, Cal., May 31, 1910 (Ray); Fort Klamath, Oreg., May 27, 1887 (Merrill); and downy young at Fort Keogh, Mont., June 8, 1889 (Thorne).

Fall migration.—In the Mississippi Valley the number of sora is probably greater than along the Atlantic coast, yet the marshes are so numerous and extensive that sora never congregate in small areas in such enormous numbers as in favorable localities on the coast.

Fall migration.

Place.	Number of years' records.	Average date of fall arrival.	Earliest date of fall arrival.
Pachaco, Chihuahua			Aug. 11, 1905
La Barca, Jalisco			Aug. 17, 1903
Negrete, Michoacan			Sept. 10, 1903
Bermuda			Aug. 31, 1847
Canaveral, Fla			Sept. 16, 1889
Ways Station, Ga			Aug. 25, 1886
Sullivans Island, S. C			Aug. 14, 1910
Raleigh, N. C	4	Sept. 2	Aug. 21, 1894
Washington, D. C	14	Aug. 13	Aug. 3, 1899
Diamond, La			Sept. 1, 1897
Bay St. Louis, Miss	3	Sept. 8	Aug. 23, 1899
Monteer, Mo. (near)	2	Sept. 8	Sept. 4, 1902
Brownsville, Tex			Sept. 18, 1888
Fort Verde, Ariz			Sept. 3, 1886

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Indian Head, Sask			Oct. 25, 1904
Aweme, Man	6	Sept. 6	Oct. 3, 1907
Ottawa, Ont			Oct. 30, 1895
Point Pelee, Ont			Oct. 14, 1909
Godbout, Que	3	Aug. 19	Sept. 14, 1891
Montreal, Canada	4	Sept. 30	Oct. 7, 1893
Southern Maine	3	Oct. 7	Oct. 26, 1904
North Truro, Mass			Oct. 20, 1889
Newport, R. I	5	Oct. 10	Nov. 10, 1899
Erie, Pa	4	Oct. 21	Oct. 25, 1894
Ossining, N. Y	2	Oct. 14	Oct. 16, 1885
Washington, D. C	5	Oct. 19	Nov. 9, 1878
Raleigh, N. C	4	Oct. 15	Oct. 30, 1891
Kirkwood, Ga			Oct. 14, 1898
Keokuk, Iowa	3	Oct. 10	Nov. 19, 1893
Delavan, Wis	3	Oct. 13	Oct. 22, 1896
Topeka, Kans			Oct. 18, 1902
Badger, Nebr			Oct. 23, 1899
Sioux Falls, S. Dak			Oct. 17, 1909
Antler, N. Dak			Oct. 12, 1908
Terry, Mont	3	Sept. 12	Oct. 17, 1908
St. George, Utah			Nov. 3, 1909
Palmer, Mich			Oct. 6, 1894
Neebish Island, Mich			Nov. 9, 1893
Vicksburg, Mich	7	Oct. 6	Nov. 17, 1902
Oberlin, Ohio			Oct. 23, 1896
Brookville, Ind			Oct. 14, 1890
Chicago, Ill	6	Oct. 11	Oct. 17, 1897

[**MEXICAN YELLOW RAIL.** *Porzana goldmani* Nelson.

The Mexican yellow rail is known only from the type specimen taken by Goldman, July 11, 1904, at Lerma, Mexico.]

[**YELLOW-BELLIED RAIL.** *Porzana flaviventris* (Boddaert).

The distribution of the yellow-bellied rail is rather peculiar. It is known in South America from Guiana to southern Brazil, but though not yet recorded from Central America nor from the rest of the Greater Antilles, it is not infrequent in Jamaica and Cuba.]

[**RUFOUS RAIL.** *Porzana rubra* Sclater and Salvin.

Recorded many years ago from British Honduras, the lower parts of Guatemala south to Duenas, and from Cozumel Island, Yucatan, the known range of the rufous

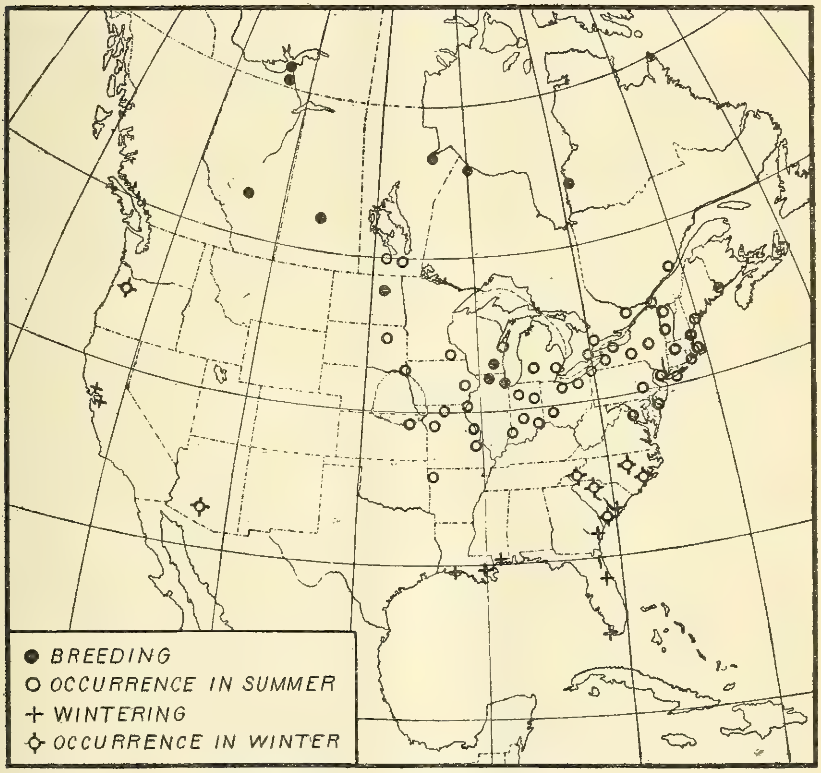

FIG. 13.—Yellow rail (*Coturnicops noveboracensis*).

rail was extended in February, 1901, to Tlacotalpam, Vera Cruz (Smith), and on April 25, 1904, by Sheldon and Piper, to Isla de los Pajaros, near Tampico, Vera Cruz.]

YELLOW RAIL. *Coturnicops noveboracensis* (Gmelin).

Range.—North America from central Canada to the Gulf coast.

Breeding range.—There seem to be only a few sets of eggs of the yellow rail in museums or collections. Hence the breeding range of the species has to be inferred from its occurrence in summer. At this season it has been noted north to Fort George, Que. (Bell), York Factory, Keewatin (Preble), and Fort Resolution, Mackenzie (Preble); and west to Red Deer, Alta. (Saunders). It has been seen during the summer south to Calais, Me. (Boardman), Winnebago, Ill. (Coues), Jefferson County, Wis. (Kumlien and Hollister), and in Minnesota (Roberts).

Winter range.—The yellow rail winters on the Gulf coast from Sandy Key, Fla. (Audubon), to Vermilion Bay, La. (McAtee); and north on the Atlantic coast to Charleston, S. C. (Wayne). Individuals have been taken casually in winter much farther north to Newbern, N. C., February, 1892 (Brimley); Sayville, N. Y., January 17, 1894 (Eaton); and Seaford, N. Y., December 4, 1908, and January 10, 1909 (Peavey). The species also has the remarkable record of appearing on the Pacific coast in winter. It does not breed anywhere west of the Rocky Mountains, but a few individuals seem to cross the mountains in migration and have been noted at Scio, Oreg., February 1, 1900 (Prill); Humboldt Bay, Cal., 1884 (Townsend); Sonoma, Cal., December 20, 1898 (Carriger); Point Reyes, Cal., November 19, 1900 (Mailliard); Cordelia, Cal. (Bryant); Martinez, Cal. (Cooper); Alameda, Cal., November 7, 1900 (Cohen); Alvarado, Cal., December 28, 1883 (Bryant); Alameda County, Cal., fall of 1897 (Kaeding); San Mateo County, Cal., November, 1897 (Taylor); Berryessa, Cal. (Beck); and Sacaton, Ariz., March 28, 1909 (Gilman).

Spring migration.—The spring advance occupies nearly two months, from late March to the middle of May. Yellow rails arrived at Fort Macon, N. C., April 12, 1871 (Coues); Washington, D. C., March 28, 1884, and April 14, 1893 (Palmer); Erie, Pa., April 23, 1904 (Todd); Princeton, N. J., April 10, 1895 (Phillips); Oakdale, N. Y., April 29, 1887 (Dutcher); Murray, N. Y., April 21, 1894 (Posson); Bridgeport, Conn., March 24, 1888 (Averill); Wakefield Meadows, Mass., May 9, 1888 (Webster); Dedham, Mass., May 26, 1906 (McKechnie); St. Louis, Mo., March 27, 1876 (Widmann); Lebanon, Ill., April 5, 1877 (Jones); Chicago, Ill., April 12, 1888 (Woodruff); Detroit, Mich., March 25, 1908 (Taverner); Lake Maxinkuckee, Ind., March 22, 1901 (Evermann); Kankakee Marsh, Ind., April 2, 1885 (Perry); Toronto, Ont., April 24, 1899 (Fleming); Two Rivers, Wis., May 22, 1890 (Fisher); Elk River, Minn., May 14, 1885 (Bailey); Lake Wilson, Minn., May 13, 1909 (Peters); Lawrence, Kans., April 18, 1885 (Goss); and Lincoln, Nebr., April 30, 1909 (Zimmer).

The species has been noted at Darien, Ga., as late as March 29, 1890 (Worthington), and at Bay St. Louis, Miss., until April 21, 1902 (Allison).

Eggs have been taken at Winnebago, Ill., May 17, 1863, and near Devils Lake, N. Dak., June 4, 1901, June 8, 1903, and June 9, 1910.

Fall migration.—The first yellow rails returned to Chester, S. C., September 3, 1887 (Loomis); Erie, Pa., September 15, 1901 (Todd); Charlestown, R. I., September 26, 1886 (Glezen); Newton, Mass., September 8, 1868 (Baird, Brewer, and Ridgway); Toronto, Ont., August 5, 1896 (Fleming); near Burlington, Iowa, September 9, 1898 (Bartsch); Lanesboro, Minn., September 1, 1886 (Hvoslef); Biloxi, Miss., November 19, 1903 (Brodie); and Bermuda, October, 1847 (Hurdis).

The last were reported from Portland, Me., October 1, 1905 (Norton); Seabrook, N. H., October 15, 1871 (specimen in U. S. National Museum); Canton, Mass., October 15, 1872 (Purdie); near New Haven, Conn., November 10, 1876 (Merriam); Buffalo, N. Y., October 11, 1907 (Eaton); Far Rockaway, N. Y., October 15, 1883 (Lawrence); Salem, N. J., October 24, 1908 (McKee); Erie, Pa., October 29, 1901 (Todd); Prince George County, Md., November 3, 1880 (Kirkwood); Washington, D. C., November 17, 1893 (Palmer); Lanesboro, Minn., September 24, 1891 (Hvoslef); Delavan, Wis., October 13, 1901 (Hollister); Kalamazoo, Mich., October 19, 1890 (Gibbs); Toronto, Ont., October 15, 1895 (Nash); Ottawa, Ont., October 22, 1895 (White); and Lawrence, Kans., October 1, 1885 (Kellogg).

BLACK RAIL. *Creciscus jamaicensis* (Gmelin).

Range.—North America from Kansas, southern Ontario, and Massachusetts, to Jamaica and Guatemala.

Breeding range.—The black rail breeds throughout the northern half of its range in the United States; it is not only the rarest rail in this district, but is also so secretive that even when present it is seldom seen, and hardly more than a dozen nests have ever been found. It occurs in summer from Mount Pleasant, S. C. (Wayne), Weaverville, N. C. (Cairns), Philo, Ill. (Hess), and Garden City, Kans. (Kellogg), north to Chatham, Mass. (Allen), Dundas, Ont. (Nash), Calumet, Ill. (Nelson), Fort Dodge, Iowa (Somes), and Beloit, Kans. (Goss). It has been taken also north to Lake Koshkonong, Wis., August 20, 1877 (Kumlien and Hollister), Westpoint, Nebr. (Bruner), and Denver, Colo. (Bruce).

Winter range.—The black rail winters in Guatemala (Salvin), and occurs in Jamaica from August to February and rarely to April (Scott). There seems to be no sure record of its wintering anywhere in the United States.

Spring migration.—The species was noted in the spring at Key West, Fla., March 11, 1890 (Scott); Warrington, Fla., March 22–26, 1885 (Stone); Mosquito Inlet, Fla., May 9, 1902 (Gane); Washington, D. C., May 29, 1891 (Brown), and June 6, 1879 (Baird, Brewer, and Ridgway); Milton Hill, Mass., May 16, 1904 (Cobb); Canton, Ill., April 15, 1895 (Cobleigh); Bicknell, Ind., May 1, 1907 (Chansler);

Carthage, Ohio, May 17, 1890 (Drury); southeastern Texas, April 29, 1879 (Nehrling); and Neosho Falls, Kans., March 18, 1886 (Goss).

Fall migration.—During the fall the black rail has visited the Bermudas, September 5, 1848 (Hurdis); Mount Pleasant, S. C., October 17, 1891. and November 9, 1906 (Wayne); Piscataway

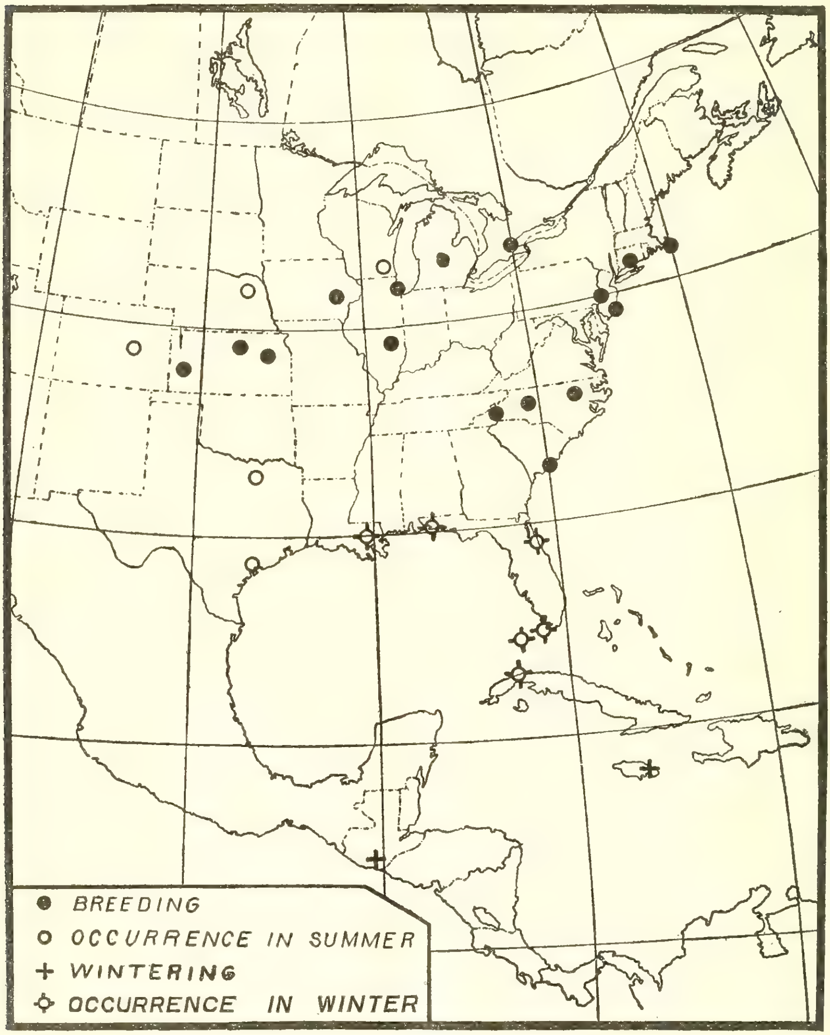

FIG. 14.—Black rail (*Creciscus jamaicensis*).

Creek, Md., September 25, 1877 (Palmer); Mount Calvert, Md., October 19, 1906, September 22, 1907, and October 12, 1908 (Palmer); Washington, D. C., September 1, 1908 (Palmer); Camden, N. J., September 22, 1887 (Sherratt); Canton, Ill., October 27, 1894 (Cobleigh); Chicago, Ill., October 15, 1903 (Dearborn); Lawrence, Kans., September 26, 1885 (Kellogg); and Habana, Cuba, twice (Gundlach).

Eggs have been found at Mount Pleasant, S. C., June 10, 1903 (Wayne); Raleigh, N. C., May 26, 1890, to August 10, 1898 (Stone); Saybrook, Conn., July 10, 1876 (Purdie); Great Island, Conn., June 6, 1884 (Clark); Calumet Marsh, near Chicago, Ill., June 19, 1875 (Nelson); Philo, Ill., May 30, 1901 (Hess); and Garden City, Kans.,

FIG. 15.—Farallon rail (*Creciscus coturniculus*).

June 6, 1889 (Kellogg). Young not long from the nest were found near Philadelphia, Pa., July 22, 1836 (Allen).

FARALLON RAIL. *Creciscus coturniculus* (Ridgway).

Knowledge of the life history of the Farallon rail is only fragmentary. The species has been found nesting in a marsh near National City, Cal. (Stephens), and apparently this is the only place where eggs have actually been collected. The nesting season extends from the middle of March to early May (Ingersoll).

The species is somewhat common in late fall in the marshes around San Francisco Bay and especially near Point Reyes (Brewster); it has been noted there from October (October 12, 1899) to December (December 1, 1892) and may possibly winter there, as one was seen February 29, 1892 (Beck), and one at Redwood City February 2, 1897 (Thayer). At their breeding grounds near San Diego they have been recorded from March to June 22 and from November 16 to December (Stephens). Other California dates are: Riverside, August 13, 1892 (Miller); Orange, December 12, 1896 (Grinnell); and Ballona Marsh, Los Angeles County, May 16, 1895 (Grinnell). The species has wandered into Washington—Tacoma, November 10, 1900 (Bowles); it was probably seen by Bendire at Malheur Lake, Oreg.; and one was taken August 31, 1905, at San Quintin, Lower California (Nelson and Goldman). Eggs have been taken in the vicinity of San Diego Bay, April 21, 1908 (Thayer); May 4, 1908 (Ingersoll); and April 7, 1910 (Thayer).

Should it be ascertained that this rail winters near San Francisco Bay and does not breed there, the species would be unique among United States birds as wintering north of the breeding grounds.

[**ASH-HEADED RAIL.** *Creciscus cinereiceps* (Lawrence).

The ash-headed rail occupies most of eastern Costa Rica and the southern half of eastern Nicaragua. Its known range was extended in 1911 by E. A. Goldman, of the Biological Survey, through the capture of a specimen at Lion Hill, Panama.]

[**WHITE-THROATED RAIL.** *Creciscus albigularis* (Lawrence).

Originally described from Panama, the white-throated rail has been recorded south to Remedias, Colombia, and north along the Pacific coast to Las Trojas and La Barranca, Costa Rica.]

[**WANDERING RAIL.** *Creciscus exilis vagans* (Ridgway).

The wandering rail has been obtained on the Segovia River, Honduras, and the Escondido River, Nicaragua. The type species occurs in northern Brazil, Guiana, and Trinidad Island.]

CORN CRAKE. *Crex crex* (Linnaeus).

Range.—Eastern Hemsiphere; casual in Greenland and to the United States.

The coast of Greenland has received several visits from the corn crake, its range here extending on the west side to Egedesminde in Disco Bay, and south to Julianehaab; and on the eastern coast it has been noted at Angmagsalik and Tasicasak. It was once taken in Bermuda—October 25, 1847 (Reid); Hursley, Md., November 28, 1900 (Laurent); Salem, N. J., fall of 1854 (Cassin); near Bridgeton, N. J., June, 1856 (Krider); Dennisville, N. J., November 11, 1905 (Stone); Oakdale, N. Y., November 2, 1880 (Dutcher); Green Island, N. Y., November 6, 1883 (Park); near Amagansett, N. Y., about August 15, 1885 Dutcher); Montauk Point, N. Y., about November 1, 1888 (Dutcher); Saybrook, Conn., October 20, 1887 (Clark); Cranston, R. I., 1857 (Howe and Sturtevant); Falmouth, Me., October 14, 1889 (Brock); Pictou, N. S., about October, 1874 (McKinlay); and Newfoundland, about 1859 (Jones). Thus there are at least 14 records of the corn crake in North America south of Greenland, all but one of them in the fall.

The species ranges across Europe and Asia east to the valley of the Yenesei, and to Maskat, Arabia. It winters in Africa.

FIG. 16.—Corn crake (*Crex crex*).

PURPLE GALLINULE. *Ionornis martinicus* (Linnaeus).

Range.—Tropical and subtropical America; north regularly to southern United States; casually to southern Canada; south through the West Indies and Central America to Ecuador and Paraguay.

The real home of the purple gallinule is in Middle America, the West Indies, and South America. In the latter country the species extends south to Iguape, Brazil (Ihering); Buenos Aires, Argentina (Dabbene); and Androas, Ecuador (Sharpe). It is common in the Lesser and Greater Antilles and throughout Middle America west to San Blas, Tepic (Lamb), to the Rio de Coahuana, Colima (Lawrence), and

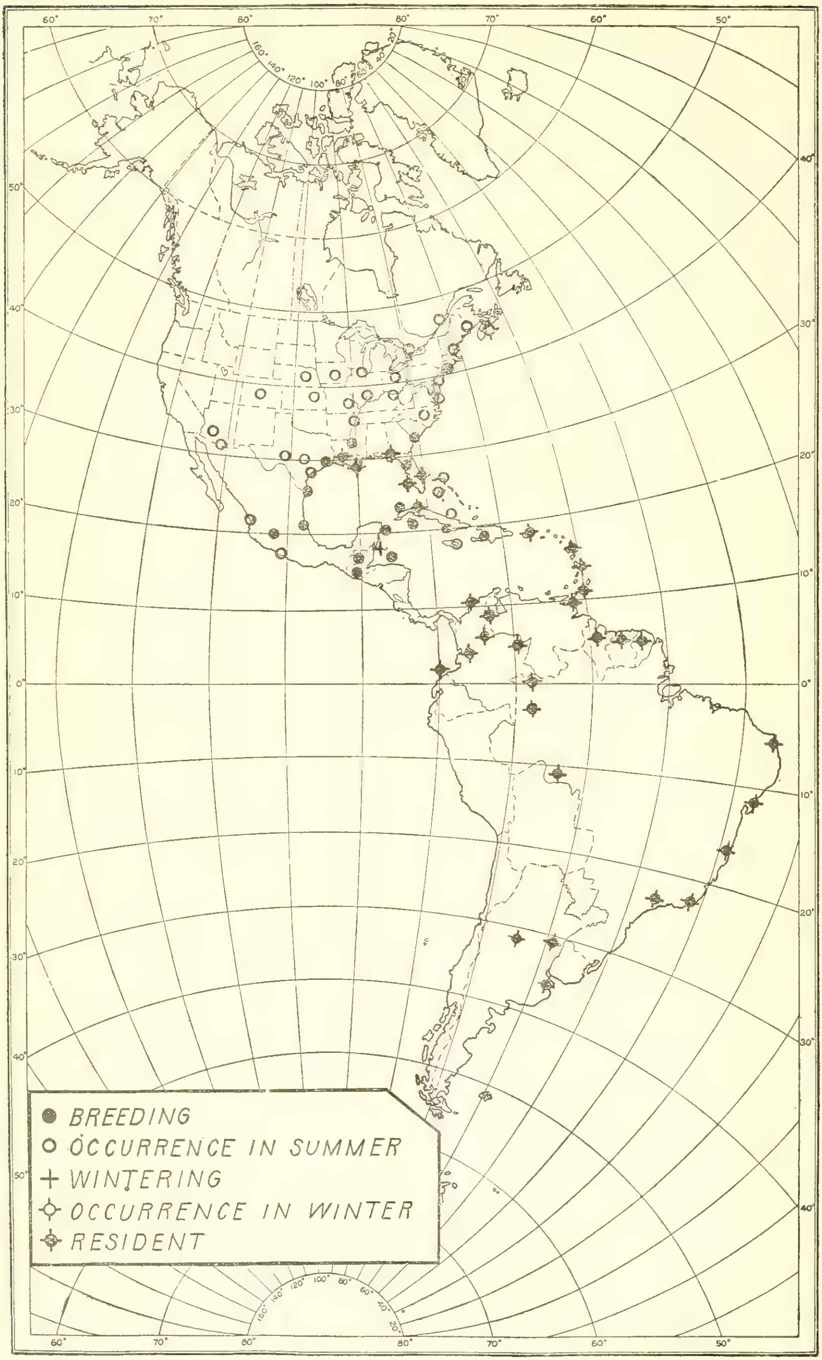

FIG. 17.—Purple gallinule (*Ionornis martinicus*).

to La Barca, Jalisco (Goldman). Throughout this great region it seems to be either resident or so slightly migrant that its movements can not be traced.

To the northward it has occurred a few times in Bermuda—May 30 and October 22, 1851 (Hurdis); and in the Bahamas, according to Bonhote, has been taken at Cay Lobos, October 19, 1900, Cay Sal, April 24, 1901, and February 9, 1902, and Mangrove Cay, December 16, 1901. It is resident in Florida and thence along the Gulf coast to Texas and eastern Mexico. Along the Atlantic coast it nests regularly north to Charleston, S. C. (Wayne), but withdraws in winter to Florida, where it is known at this season north to Tallahassee (Williams). It breeds up the Mississippi River to Natchez, Miss. (Audubon), but seems to retire to the Gulf coast for the winter.

The purple gallinule is a great wanderer and has been taken in the spring at Rockport, Mass., April 12, 1875 (Whitman); Randolph, Mass., May 24, 1904 (Thayer); South Lewiston, Me., April 11, 1897 (Knight); near St. John, N. B., April 6, 1881 (Brewster); Halifax, N. S., April, 1889 (Piers); St. Charles, Mo., April 22, 1877 (Widmann); in Illinois near St. Louis, Mo., April 18, 1877 (Allen); Coal City, Ill., April 24, 1900 (Deane); Willington, Ill., April 26, 1909 (Deane); near Chicago, Ill., May, 1866 (Nelson); Sandusky, Ohio, April 28, 1896 (Moseley); near Toronto, Ont., April 8, 1892 (Nash); Janesville, Racine, and Milwaukee, Wis. (Kumlien and Hollister); Blackhawk, Iowa (Peck); Huntsville, Tex., April 26, 1909 (Thomason); Manhattan, Kans., April 14, 1893 (Lantz); Westpoint, Nebr. (Bruner); Tombstone, Ariz., June, 1904 (Willard); and Florence, Colo., June 17, 1911 (Doertenbach).

The latest dates in the fall north of the breeding grounds are at Quebec City, Canada, middle of September, 1909 (Dionne); Mount Desert Island, Me., November 7, 1899 (Swain); Stoneham, Mass., November 27, 1837 (Peabody); Sandusky, Ohio, September 2, 1894 (Tuttle); Waverly, Ohio, November 16, 1898 (Henninger); Fredericksburg, Tex., September 18, 1894 (Grasso); and Tucson, Ariz., October 20, 1887 (Brown). There are also the strange records of single birds found at Halifax, N. S., January 30, 1870 (Jones), and January 16, 1896 (Piers).

At the southern limit of the purple gallinule's range in Brazil the eggs are laid in November (Euler), and at Santiago del Estero, Argentina, a set was taken December 28, 1905 (Hartert and Venturi); in Cuba eggs are found most commonly in June and July (Gundlach); while in the United States the breeding season is long extended, since eggs are in the U. S. National Museum, collected at Avery, La., April 15, 1894, while downy young were taken at Yemassee, S. C., September 17, 1887 (Wayne).

FLORIDA GALLINULE. *Gallinula galeata* (Lichtenstein).

Range.—North and South America; north to California, Minnesota, and Quebec; south through the West Indies and Central America to Chile and Argentina.

Breeding range.—The Florida gallinule has a wide distribution in the Western Hemisphere, breeding throughout the West Indies and in South America south to La Concepcion, Chile (Gould and Darwin), and to Buenos Aires, Argentina (White). It is almost entirely absent from northwestern Colombia and the whole of Panama and Costa Rica, but is common in favorable localities of the rest of Middle America north to Tepic and Mazatlan (Lawrence), and to Brownsville, Tex.

The summer distribution in the United States is peculiar, comprising three distinct areas. The largest area occupies the district from the Ohio River and the mouth of the Delaware north to Provincetown, Mass. (Small), St. Albans, Vt. (Woodworth), Montreal, Canada (Wintle), Toronto, Ont. (Nash), Lansing, Mich. (Cole), Kelley Brook, Wis. (Schoenebeck), and Minneapolis, Minn. (Moore); and west to Valentine and North Platte, Nebr. (Bruner, Wolcott, and Swenk). The second area includes Florida and the Gulf coast west to Louisiana and north to Rodney, Miss. (Mabbett), and to Charleston, S. C. (Wayne) This Florida area connects southward with Cuba and the Greater Antilles, where the species is common, but to the eastward in the Bahamas the bird seems to be rare and local, though it has been recorded at Nassau (Bonhote), Watlings (Todd), and at Inagua (Cory). It breeds rarely in Bermuda, and additional migrants appear there in the fall (Reid). The remaining area is western California from Escondido (Sharp) to Sacramento (Ridgway).

Each of these three areas is separated from its nearest neighbor by several hundred miles in which the species is rare or unknown. Between the first and second is an isolated breeding colony at Lake Ellis, N. C. (Philipp). The birds that breed at Woodward, Okla. (Lantz), may constitute a far removed outpost from the lower Missouri contingent, while the few individuals nesting in the vicinity of Tucson, Ariz. (Rhoads), are separated by many miles of desert from their nearest neighbors in southern California.

A few Florida gallinules have wandered north to Halifax, N. S., November 18, 1888 (Austen); Kentville, N. S., September 20, 1886 (Chamberlain); St. John, N. B., September, 1880 (Brewster); Calais, Me. (Boardman); Quebec City, Canada, May 28, 1892 (Dionne); Beaumaris, Ont. (Fleming); Bay City, Mich., May 2, 1891 (Eddy); near Vermilion, S. Dak., late April, 1899 (Sweet); Colorado Springs, Colo., May 9, 1882 (Allen and Brewster); and near Fort Verde, Ariz., September 26, and November 1, 1884 (Mearns).

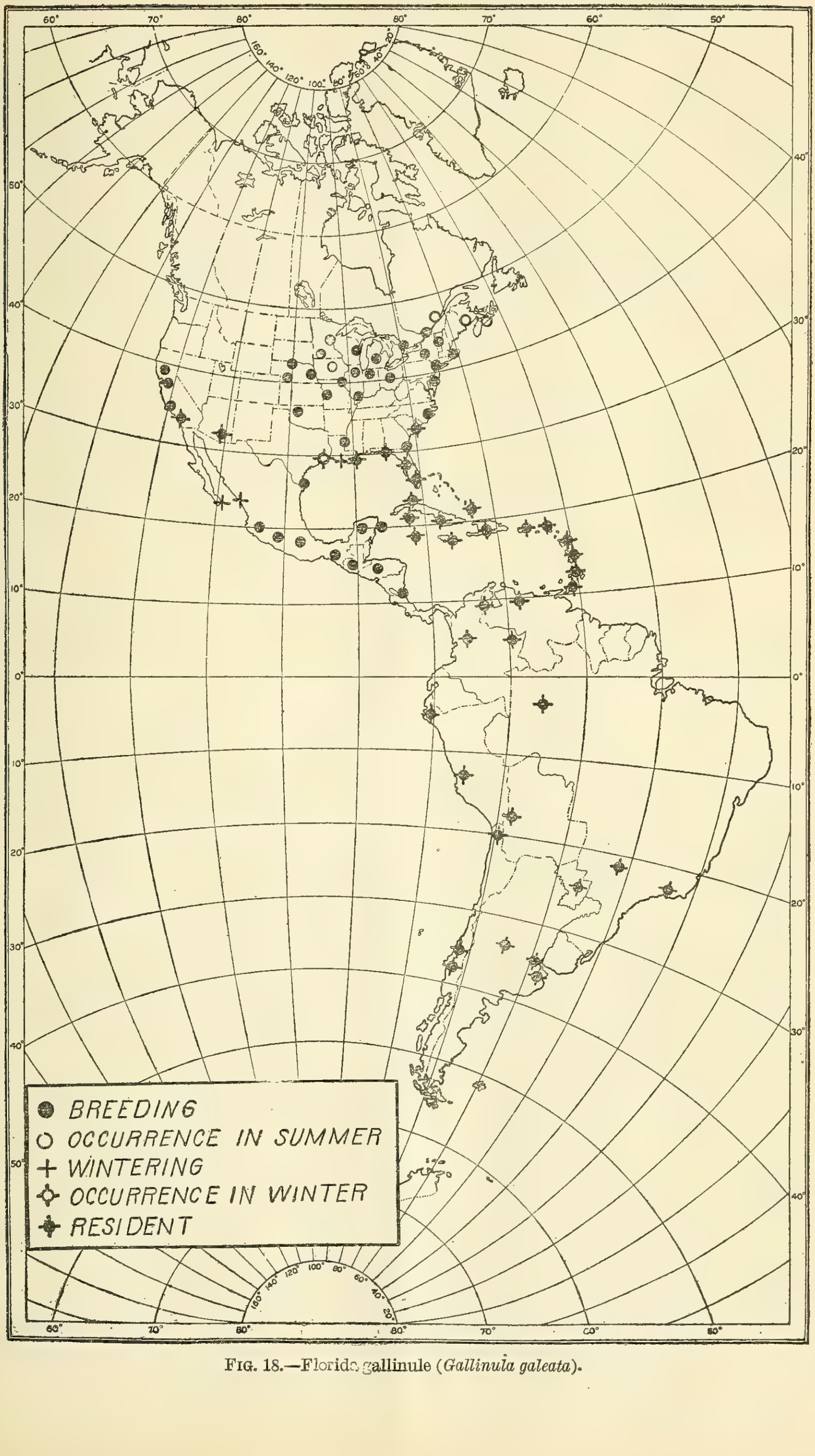

FIG. 18.—Florida gallinule (*Gallinula galeata*).

Winter range.—The Florida gallinule seems to be resident throughout its range in Middle and South America and north to Ashepoo Station, S. C., December 30 and 31, 1904 (Murphy); Tallahassee, Fla. (Williams); Vermilion Bay, La. (McAtee); Lake Surprise, Texas, December 8–11, 1910 (McAtee); San Pedro, Ariz. (Scott); and Los Angeles, Cal. (Swarth). A laggard was noted at Palmer, Mass., December, 1909 (Morris).

Spring migration.—The Florida gallinule arrived at Washington, D. C., April 19, 1892 (Hasbrouck); Waynesburg, Pa., April 26, 1894 (Jacobs); Philadelphia, Pa., average April 23, earliest April 16, 1909 (Miller); Canandaigua, N. Y., April 12, 1905 (Antes); Cambridge, Mass., April 29, 1895 (Faxon); Ferrisburgh, Vt., April 28, 1879 (Robinson); East Sullivan, Me., May 5, 1883 (Knight); Montreal, Canada, May 19, 1892 (Wintle); Versailles, Ky., April 11, 1905 (Brodhead); Chicago, Ill., average May 9, earliest April 24, 1902 (Blackwelder); central Indiana, average May 2, earliest April 29, 1908 (Ratliff); New Bremen, Ohio, April 19, 1909 (Henninger); Oberlin, Ohio, average May 2, earliest April 20, 1907 (Jones); Vicksburg, Mich., average May 2, earliest April 24, 1904 (Corwin); Dunnville, Ont., May 8, 1884 (McCallum); Grinnell, Iowa, April 28, 1890 (Kelsey); National, Iowa, April 18, 1909 (Sherman); near Madison, Wis., average May 1, earliest April 26, 1908 (Vorhies); Minneapolis, Minn., May 10, 1905 (Moore); Lawrence, Kans., April 19, 1907 (Hanna); Dunbar, Nebr., April 27, 1899 (Wolcott). Near the southern limit of the breeding range at Sacaya, Chile, the species nests up to 11,000 feet altitude and the eggs are here laid during January and February (Lane); at Concepcion, Argentina, young were found September 29 and eggs the middle of October, 1880 (Barrows); and at Cantagallo, Brazil, young in late October, and eggs January 28, (Euler). It is thus evident that south of the Equator the breeding season lasts about six months from September to February. Nearly the whole year is represented north of the equator, for young 10 days old were found in Jamaica January 23, 1891, and eggs in May and June (Scott); while in Barbados eggs were taken July, 1888 (Fielden); and in Cuba, according to Gundlach, the gallinule nests from June to December. Eggs were found at Mount Pleasant, S. C., May 21, 1904 (Wayne); Philadelphia, Pa., May 22, 1905 (Miller); Stratford, Conn., June 25, 1891 (Lucas); North Truro, Mass., May 22, 1892 (Thayer); Cambridge, Mass., June 5, 1890 (Brewster); Lake Bomaseen, Vt., May 28, 1881 and 1882 (Richardson); Rodney, Miss., May 10, 1887 (Mabbett); Kalamazoo, Mich., May 25, 1891 (White); Dunnville, Ont., May 29, 1884 (McCallum); Pewaukee, Wis., May 20, 1875 (Goss); Fort Snelling, Minn., May 28, 1903 (specimens in U. S. National Museum); Brownsville, Tex., May 16, 1877 (Sennett); and near Los Angeles, Cal., April 15, 1890 (Howard).

Fall migration.—The latest birds noted at Point Pelee, Ont., were seen October 9, 1906 (Taverner and Swales); Vicksburg, Mich., average October 1, latest November 16, 1910 (Corwin); Oberlin, Ohio, November 11, 1890 (Jones); New Bremen, Ohio, November 16, 1909 (Henninger); Calumet, Ill., October 23, 1876 (specimen in U. S. National Museum); St. Louis, Mo., October 3, 1905 (Widmann); Montreal, Canada, November 5, 1898 (Wintle); Portland, Me., October 15, 1907 (Norton); Cambridge, Mass., November 9, 1898 (Hathaway); Point Judith, R. I., November 29, 1900 (Hathaway); Shelter Island, N. Y., October 28, 1898 (Worthington); Washington, D. C., October 26, 1876 (Jouy); and Philadelphia, Pa., November 16, 1909 (Miller).

EUROPEAN COOT. *Fulica atra* Linnaeus.

The normal range of the European coot includes most of Europe, the northern part of Africa, northern and central Asia, India, and southeast to the Philippines.

A few specimens have been taken in southern Greenland, where it is an accidental visitant.

COOT. *Fulica americana* Gmelin.

Range.—North America from central British Columbia, southern Mackenzie and Quebec, south through the West Indies and Central America to Panama.

Breeding range.—During the breeding season the coot shuns southeastern United States and the lower Mississippi Valley, while it breeds abundantly in the same latitudes of western United States and even south in Mexico to Jomatla, Vera Cruz (Sharpe), and Acapulco, Guerrero (Nelson). There are more or less isolated breeding colonies on Cozumel Island, Yucatan (Sharpe), and the Lake of Duenas, Guatemala (Salvin and Sclater), while the species is a common breeder in Jamaica (Scott) and in Porto Rico (Wetmore). The coot is a rare breeder along the Atlantic coast, but a few pairs have been known to nest from Philadelphia, Pa. (Miller), north to Long Island City, N. Y. (Braislin), and according to Nuttall it nested once near Cambridge, Mass., but it is not now known to breed anywhere on the New England coast. It has nested at Lake Bomaseen, Vt. (Howe), and is a common breeder west of the Alleghenies south to Ithaca, N. Y. (Reed and Wright), Port Clinton, Ohio (Langdon), Mount Carmel, Ill. (Ridgway), Reelfoot Lake, Tenn. (Rhoads), and Eureka Springs, Ark. (Smith), whence the breeding range extends southwest through Decatur, Tex. (Donald) to Brownsville, Tex. (Merrill). On the Pacific coast the species breeds south in Lower California to Purisima (Thayer). It may occasionally breed in southern Louisiana, for some twenty birds were seen June 19, 1914, on the southern side of Lake Ponchartrain (Fisher).

Northward the coot breeds to Quebec City, Canada (Dionne), Ottawa, Ont. (White), Sudbury, Ont. (Alberger), Kelley Brook, Wis.

(Schoenebeck), Oak Point, Man. (Small), Chemawawin, Keewatin (Nutting), Prince Albert, Sask. (Ferry), Fort Simpson, Mackenzie (Preble), and Caribou District, B. C. (Brooks). It has been known to wander north to New Brunswick (Chamberlain), Nova Scotia (Downs), St. John, Newfoundland (Hawley), Sandwich Bay, Que. (Grenfell),

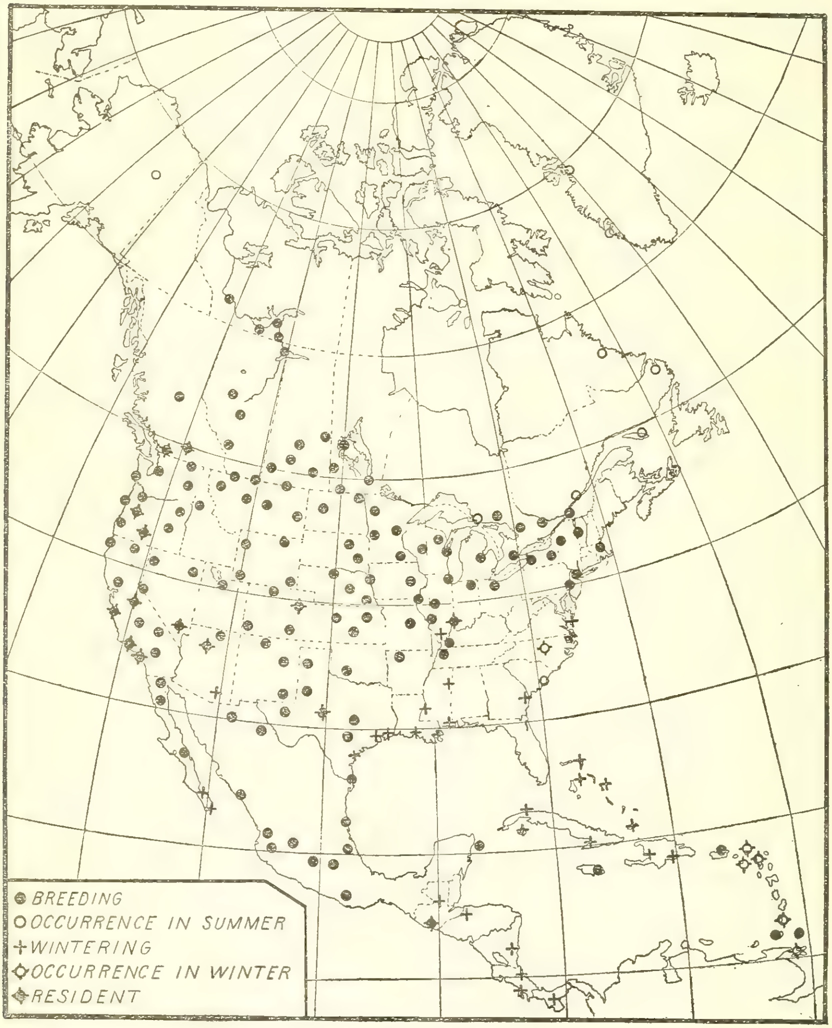

FIG. 19.—Coot (*Fulica americana*).

Nain, Que. (Turner), Jacobshavn, Greenland, 1854 (Harting), Godthaab, Greenland, 1854 (Newton), Fort Yukon, Alaska (Nelson), and Sitka, Alaska (Hartlaub).

Winter range.—The coot migrates south in winter through Central America to Lagunadel Castillo, Panama (Salvin), and to the northern

Bahamas, Cuba, and Haiti. It winters in southern United States, north on the Atlantic coast to Cobb Island, Virginia (Rives), in the interior to Mount Carmel, Ill. (Ridgway), San Angelo, Tex. (Lloyd), San Pedro, Ariz. (Scott), Pecks Lake, Ariz. (Mearns), and St. Thomas, Nev. (Bailey); and along the whole Pacific coast from San Jose del Cabo, Lower California (Frazar), to Chilliwack and Okanogan, B. C. (Brooks). It has been noted in winter near Cambridge, Mass. (Brewster), Buckhannon, W. Va. (Day), and at Barr Lake, Colo. (Hersey and Rockwell), and in late fall migration in Bermuda (Hurdis), and on Clipperton Island, southwest of Mexico (Beck).

Spring migration.

Place.	Number of years' records.	Average date of spring arrival.	Earliest date of spring arrival.
Raleigh, N. C			Apr. 6, 1898
Scott Depot, W. Va	3	Mar. 19	Mar. 15, 1907
Gunpowder Marsh, Md			Mar. 14, 1893
Renovo, Pa			Mar. 5, 1900
Erie, Pa			Mar. 28, 1898
Branchport, N. Y. (near)	4	Apr. 22	Apr. 12, 1888
Cambridge, Mass			Apr. 18, 1890
Montreal, Canada			Apr. 28, 1893
Quebec City, Canada			May 14, 1890
Knoxville, Tenn			Mar. 27, 1909
Versailles, Ky			Mar. 24, 1904
Central Missouri	9	Mar. 17	Feb. 23, 1898
Southern Illinois	3	Mar. 15	Feb. 26, 1890
Lake Maxinkuckee, Ind			Jan. 10, 1901
English Lake, Ind			Feb. 14, 1891
Brookville, Ind	6	Mar. 31	Mar. 26, 1888
Chicago, Ill	7	Mar. 25	Mar. 19, 1886
Rockford, Ill	7	Apr. 4	Mar. 19, 1891
Waterloo, Ind	4	Apr. 9	Mar. 17, 1907
Oberlin, Ohio	9	Apr. 2	Mar. 9, 1908
Vicksburg, Mich	7	Mar. 28	Mar. 19, 1904
Southern Ontario	5	Apr. 23	Mar. 15, 1885
Ottawa, Ont	3	May 3	Apr. 27, 1892
Keokuk, Iowa	6	Mar. 28	Mar. 13, 1900
Sioux City, Iowa	7	Mar. 25	Mar. 21, 1909
Laporte, Iowa	5	Mar. 30	Mar. 16, 1886
Delavan, Wis	3	Mar. 26	Mar. 24, 1894
La Crosse, Wis	6	Apr. 2	Mar. 25, 1910
Heron Lake, Minn	8	Apr. 1	Mar. 16 1894
Lanesboro, Minn	4	Apr. 18	Apr. 16, 1892
Minneapolis, Minn	5	Apr. 19	Apr. 15, 1906
White Earth, Minn	3	May 2	May 1, 1880
Manhattan, Kans			Mar. 19, 1897
Onaga, Kans	5	Apr. 12	Mar. 31, 1903
Southeastern Nebraska	4	Apr. 3	Mar. 18, 1909
Southeastern South Dakota	7	Apr. 7	Mar. 27, 1910
Reaburn, Man	8	Apr. 28	Apr. 17, 1895
South Qu'Appelle, Sask	6	Apr. 25	Apr. 20, 1908
Osler, Sask			May 1, 1893
Fort Vermilion, Alta			May 8, 1909 and 1911.
Fort Simpson, Mackenzie			June 1, 1905
Gila City, Ariz			Mar. 1, 1894
Camp Grant, Ariz			Mar. 20, 1869
Boulder, Colo			Feb. 27, 1904
Loveland, Colo	3	Mar. 21	Mar. 10, 1887
Cheyenne, Wyo			Apr. 12, 1888
Rathdrum, Idaho	2	Apr. 26	Apr. 25, 1903
Great Falls, Mont			Apr. 26, 1892
Chilliwack, B. C	3	Apr. 10	Rare, winter.

The coot is reported to remain in northern Florida to May 2, 1908, average, April 30; Canaveral, Fla., April 29, 1889; Washington, D. C., May 2, 1904; southern Louisiana, May 18, 1898, average, April 18; Bay St. Louis, Miss., May 10, 1902; and Brookville, Ind., May 16, 1884.

Eggs of the coot have been reported at Newark, N. J., May 30, 1907 (Abbott); Ithaca, N. Y., May 25, 1907 (Reed and Wright); Kewanee, Ill., May 22, 1893 (Muchison); Terre Haute, Ind., May 19, 1888 (Blatchly); English Lake, Ind., May 11, 1890 (Deane); Agricultural College, Mich., May 15, 1897 (Hankinson); Dunnville, Ont., June 1, 1884 (McCallum); Fort Snelling, Minn., May 27, 1891 (specimens in U. S. National Museum); Brownsville, Tex., May 16, 1877 (Sennett); Decatur, Tex., May 19, 1889 (Donald); Barr Lake, Colo., April 27–July 21, 1907 (Rockwell); Long Lake, Man., June 5, 1894 (Arnold); Fort Chippewyan, Alta., June 7, 1880 (MacFarlane); Purisima, Lower California, May 17, 1909 (Thayer); Escondido, Cal., April 20, 1903–July 1, 1906 (Sharp); and Fort Klamath, Oreg., May 13, 1878 (Merrill).

Fall migration.

Place.	Number of years' records.	Average date of the last one seen.	Latest date of the last one seen.
Montreal Canada	3	Oct. 18	Oct. 24,1892
Ottawa, Ont	5	Oct. 17	Oct. 23,1909
Southern Maine	5	Oct. 13	Oct. 24,1904
Durham, N. H			Oct. 10,1897
Cambridge, Mass			Dec. 20,1903
Newport, R. I	4	Nov. 7	Dec. 20,1900
Portland, Conn			Nov. 14,1892
Branchport, N. Y	2	Nov. 11	Nov. 22,1896
Renovo, Pa	7	Oct. 25	Nov. 2,1894
Washington, D. C	4	Oct. 21	Oct. 31,1899
Winfield, W. Va			Nov. 12,1907
Raleigh, N. C			Dec. 1,1882
South Qu'Appelle, Sask			Oct. 21 1907
Aweme, Man			Oct. 15 1909
Sioux Falls, S. Dak	3	Nov. 11	Nov. 14 1909
Lincoln, Nebr	2	Nov. 14	Nov. 18 1900
Onaga, Kans	2	Oct. 23	Oct. 26 1899
Minneapolis, Minn	3	Oct. 17	Nov. 6 1906
Lanesboro, Minn			Nov. 10 1892
Madison, Wis			Nov. 24 1909
Chicago, Ill	4	Oct. 17	Nov. 6 1906
New Harmony, Ind	2	Oct. 21	Oct. 27,1902
Oberlin, Ohio	2	Oct. 15	Nov. 26,1906
Vicksburg, Mich	6	Nov. 19	Dec. 5 1909
Keokuk, Iowa	5	Nov. 12	Dec. 21,1899
Kansas City, Mo			Nov. 23,1904
Sawtooth Lake, Idaho			Oct. 2,1890
Terry, Mont			Oct. 4,1903
Mosca, Colo. (near)			Nov. 5 1907
Chattanooga, Okla			Nov. 28,1904

The first coot arrives in northern Florida, in the fall, on the average October 20, earliest October 17, 1908; Washington, D. C., September 20, earliest September 1, 1890; Erie, Pa., September 6, earliest September 5, 1875; Winfield, W. Va., August 20, 1907; Cambridge, Mass., August 16, 1895; Rodney, Miss., September 24, 1888; Jasper City, Mo., September 20, 1902; and Clipperton Island, southwest of Mexico, November 19, 1901.

[**CARIBBEAN COOT.** *Fulica caribaea* Ridgway.

The Caribbean coot is recorded from the Lesser Antilles on the islands of Anguilla, Guadeloupe, and St. John.]

[**AMERICAN FINFOOT.** *Heliornis fulica* (Boddaert).

The American finfoot ranges from Matto Grasso, Brazil, and Pebas, Peru, north through Guiana, Venezuela, Ecuador, Colombia, and Central America to the Belize River, British Honduras, the Coatzacoalcos River, and Buena Vista, Vera Cruz.]

[**GUATEMALAN SUN BITTERN.** *Eurypyga major* Hartlaub.

Ranging into northern South America, in Colombia and Ecuador, the Guatemalan sun bittern is rare in Central America, where it has been recorded from Panama, Costa Rica (both coasts), and from the mountains southeast of Coban, Guatemala.]

INDEX.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 129

Contribution from the Forest Service, Henry S. Graves, Forester.
September 10, 1914.

(PROFESSIONAL PAPER.)

YIELDS FROM THE DESTRUCTIVE DISTILLATION OF CERTAIN HARDWOODS.[1]

By L. F. Hawley and R. C. Palmer, *Chemists in Forest Products.*

PURPOSE OF EXPERIMENTS.

The chief hardwoods used in this country for distillation are beech, birch, and maple. Only mill and forest waste and trees unmerchantable for lumber are now ordinarily used, although some material suitable for lumber still finds its way to the distillation plants. Such southern hardwoods as the oaks, red gum, tupelo, and hickory have not been important in distillation, and no information has existed in regard to the amount of the various products which could be obtained from them. Nor has information been available on the relative value of the commonly used species, or of the different forms of material, such as body wood, limbs, and slabs. The investigation here described was undertaken in order to supply this information and to aid in this way the utilization of materials now wasted.

METHOD OF INVESTIGATION.

GENERAL PLAN.

Since conditions of distillation influence the yield of products, results obtained in the laboratory could not be compared directly with those obtained in commercial operations. In order to have a direct comparison between the species commonly used and the ones which are not, it was therefore necessary to include both classes in the investigation.

The various materials were distilled under similar conditions, and their products analyzed by the same methods. In order to avoid errors due to differences in yields from different trees of the same species, in most cases an average sample of material from two or

Note.—Gives results of experiments in destructive distillation of hardwoods. Of interest to manufacturers of by-products.

[1] The investigation the results of which are given in this bulletin were conducted at the Forest Products Laboratory, Madison, Wis., maintained in cooperation with the University of Wisconsin.

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three trees was distilled. Further, the average yields from the heartwood[1] of several trees were in a few instances compared with the yields from lumber of the same species. Differences in yields may also occur in trees of the same species grown in different localities, and for this reason the results obtained are averaged separately when more than one locality is represented. At least two distillations were made of each kind or form of material tested.

Different forms of wood—such as body wood (wood free from bark), slabs, limbs, etc.—were distilled, but the proportion of each used in commercial practice varies with different plants and localities, so that it is not possible to assume a proportion representing average conditions. For this reason the yields from different forms of wood of the same species are presented separately. The corresponding yield per given weight of wood, made up of any proportion of the various forms, can readily be calculated. However, as a basis of comparison between the species, the average yields from all heartwood runs (including lumber) are taken arbitrarily as the species value. The mean of the heartwood and slab-wood yields is also given wherever both forms were distilled.

THE RETORT.

Figure 1 shows the construction of the retort in which the distillations were made. The retort proper *A* was surrounded by the oil jacket *B*, which was filled with a high-flash-test cylinder oil. The outlet pipe *C* connected the retort with an ordinary worm condenser (not shown). The pyrometer tubes, 1, 2, 3, 4, and 5, made it possible to measure the temperature at various places within the retort. The retort was mounted on an iron stand, was insulated on all sides, and heated by a row of gas burners underneath. The flames from the burners played chiefly up one side of the cylinder and induced a fairly good circulation of the hot oil around the retort.

PREPARATION OF MATERIAL.

The forms of material used varied to some extent with different species, but most of them consisted of round bolts. These were sawed into slabs and heartwood in about the same proportion as would occur in ordinary sawmill practice, and the percentage of bark on the slabs was roughly determined. Sticks were prepared from 6 to 8 square inches in cross section and a trifle less than 18 inches long. Just before each charge of wood was weighed, six 1-inch sections, each cut from a different stick and in each case from a different part of the stick, were taken for moisture determinations.

In the comparative distillations on bark and sapwood the material was taken from the same bolts. When limbs were used they were

[1] The term "heartwood" as used in this paper applies to the material left after the slabs have been removed from a bolt or log. It was in all cases entirely free from bark, but small amounts of sapwood sometimes remained. Lumber is considered as made from heartwood as thus defined.

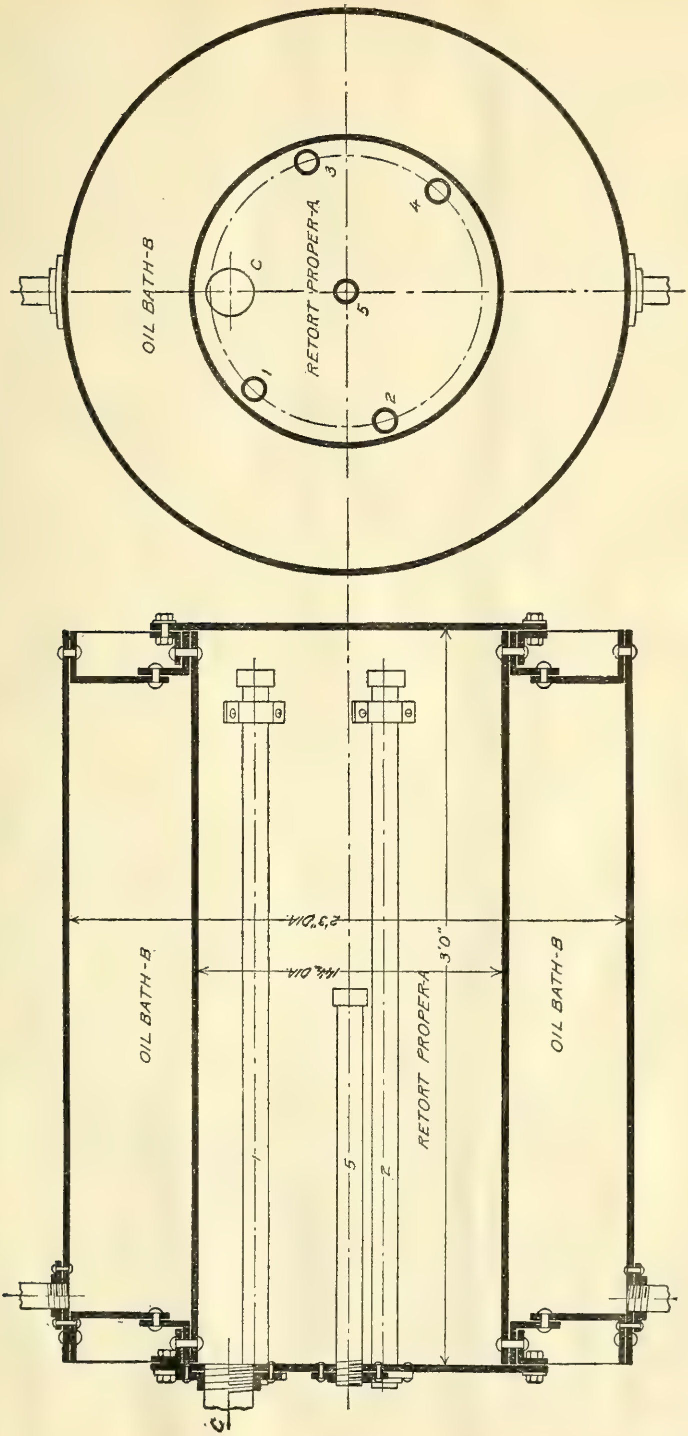

FIG. 1.—Experimental retort.

taken from the same trees as the body wood. In the case of factory waste or lumber there was, of course, no record of the trees from which the material came.

TEMPERATURES OF DISTILLATION.

It was found that the temperatures in pyrometer tubes 1, 2, 3, and 4, which are all near the surface of the retort, were always within 15° to 20° of each other, and usually within 10° during the last part of the distillation. Tube 1 was the hottest and tube 5 the coolest. It was, therefore, considered unnecessary to take temperature readings in tubes 2, 3, and 4, and the records contain the readings from tubes 1 and 5 only.

The maximum temperatures obtained in the various distillations ranged from 327° C. to 415° C., and the maximum temperatures near the surface and at the center of the retort often differed as much as 60° C. in the same distillation. These differences, however, did not appreciably affect the yields of alcohol and acetic acid, since in some instances higher temperatures gave higher yields, and in others lower. It is also found that the charcoal from low-temperature distillations, when redistilled in small samples at temperatures above 400° C., produced only small amounts of acetic acid (equivalent to an increase of 2 per cent of the original yield of acid). It was considered, therefore, that the distillations were practically complete, as to alcohol and acetic acid, provided all parts of the charge had been subjected to a temperature of at least 320° C.[1]

In most of the distillations, on account of the exothermic character of the reaction, the temperature at the center of the retort finally became higher than that at the surface. It was the heat developed during the exothermic reaction which made it difficult to obtain the same maximum temperatures in all distillations; after the reaction was well started at the surface its progress toward the center was spontaneous and the maximum temperature could not be fully controlled.

The maximum temperature was usually kept below 260° C. until the water was nearly all expelled from the wood and the temperature at the center had risen to about 190° C., when it was allowed to rise more rapidly. Only in this way could the temperatures at different points in the retort be kept near one another. By this means also the possible effect of variation in moisture content was minimized, since the slow preliminary heating resulted in a partial drying of the wood, and the different charges had therefore nearly the same moisture content at the time the destructive distillation began.

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[1] See Klason, von Heidenstam and Norlin, Arkiv for Kemi Min. och Geol. 1908, III, 9.

TABLE 1.—*Sample data sheet.*

Shipment No. 197.
Sample Nos. 21 and 22.
January 14, 1913.
Actual weight of charge 69.86 pounds.
Dry weight of charge 63.10 pounds.

Project No. 152.
Run No. 97.
Birch slab wood.
10 per cent to 14 per cent bark.

Time.	Temperature.		Total distil-late.	Remarks.
	Tube No. 1.	Tube No. 5.		
January 13.	°*C.*	°*C.*	*c. c.*	
4.30 p. m.	----------	20	----------	Retort charged; gas on one-half.
January 14.				
8.20 a. m.	234	180	3,200	Gas on full.
10 a. m.	280	220	4,200	
10.50 a. m.	303	246	5,700	
11.06 a. m.	312	263	6,700	
11.16 a. m.	317	278	7,700	
11.22 a. m.	322	291	8,700	
11.27 a. m.	329	305	9,700	
11 33 a. m.	336	318	10,700	Gas off.
11.40 a. m.	342	325	11,700	
11.51 a. m.	342	351	12,700	
12 a. m.	344	370	13,200	
12.06 a. m.	341	378	13,500	
12.11 a. m.	339	379	----------	Maximum temperature.
12.15 a. m.	337	376	----------	
1.50 a. m.	282	284	14,000	
January 15.				
8 a. m.	----------	50	14,200	

Total distillate=32.83 pounds.

COLLECTION AND ANALYSIS OF PRODUCTS.

A typical data sheet is shown in Table 1. The time and temperatures were read as every liter or half liter of distillate was collected. In a few distillations separate titrations for acetic acid were made on the first several fractions of one-half liter or one liter each, but in general all the distillate was mixed for analysis.[1] The distillate was allowed to settle for at least 24 hours. At the end of that time the tar and pyroligneous acid were separated by decantation, and the volume and weight of each determined. The charcoal was allowed to cool in the retort over night, and was weighed after separation from the "tar coke." Tar coke refers to the material occurring in the retort that was clearly a residue from the distillation of tar. This was weighed separately. The gas was computed by difference, and no determination of its composition was made.

PYROLIGNEOUS ACID.

The pyroligneous acid was analyzed by the methods described by Klar [2] for the determination of acetic acid, wood alcohol, and dis-

[1] The acetic acid in that part of the distillate (consisting usually of water) which came over before true destructive distillation began amounted to from 8 to 10 per cent of the total acetic acid; the alcohol in the same part amounted to about 1 per cent of the total alcohol. The volatile acids obtained at temperatures below the point at which the wood begins to distill destructively, say 280° C., must have an origin differ-ent from that of the acid obtained during the destructive distillation. It is probably formed by action of the water on the wood fiber at high temperatures similarly to the acid obtained by hydrolysis as reported by Cross (Dissertation, Göttingen, 1910).

[2] Technologie der Holzverkohlung, p. 337.

solved tar. For the acetic-acid and dissolved-tar determinations 100 c. c. of pyroligneous acid were distilled at a maximum temperature of 140° C. until practically no further distillate appeared, when 50 c. c. of water were added and distilled off as before. The residue in the flask was weighed and computed as dissolved tar, while for the acetic-acid determination an aliquot part of the distillate was titrated with normal sodium hydroxide solution, with phenolphtalein as indicator.

The wood alcohol was determined by distilling 60 per cent from a 1-liter sample of the pyroligneous acid and adding an excess of sodium hydroxide to the distillate, again distilling 60 per cent, and after again adding sodium hydroxide, making a third distillation of 60 per cent. The final distillate was accurately weighed, and the specific gravity determined by means of a Westphal balance at room temperature and corrected to 15° C. by using the tables of Dittmar and Fawsitt.[1] In correcting the specific gravity for temperature it is necessary to consider both the concentration of alcohol and the range of temperature.

TAR.

The amount of acetic acid in the settled tar was determined, after Klar, by distilling 100 grams of the tar at 130° to 140° until the watery distillate ceased, then passing steam through the residue until no more acid was found in the distillate, the latter being then titrated, as in the pyroligneous-acid analysis, and added to that found in the pyroligneous acid.

COMPUTATION OF RESULTS.

All the yields of products were first computed to a percentage of the dry weight of the material distilled, since only on this basis are the results directly comparable, the effect of varying percentages of moisture in air-dry wood and of differences due to weight per unit volume being eliminated. But because the unit of measurement for wood is the cord, and the capacity of a plant is naturally expressed in this unit, a comparison between the various species is made also on the cord basis. A cord was assumed to contain 90 cubic feet of actual wood, and its weight was derived from the average weight per cubic foot of air-dry wood of different species as given by Snow.[2]

The actual volume of a cord differs, of course, for different forms of material, due to variation in diameter and shape among the individual pieces. Also, differences in density exist between wood from different parts of the tree and between wood and bark; hence between forms of material containing different proportions of wood and bark. For these reasons it was impossible to estimate closely the weight per cord of the several forms as compared with each other, and the

[1] Trans. Roy. Soc. Edin., vol. 33. Quoted in Smithsonian Physical Tables.

[2] The Principal Species of Wood, by C. H. Snow.

weight is therefore assumed to be the same for all forms, and the yields per cord computed on this basis.

For comparison with commercial conditions it is better also to express the yields per cord in terms of commercial products, and so they are computed as 82 per cent crude wood alcohol and 80 per cent gray acetate of lime.

YIELDS ON PERCENTAGE WEIGHT BASIS.

ALCOHOL AND ACETIC ACID.

VARIATION AMONG SPECIES.

The average yields of total acetic acid and wood alcohol, expressed in percentages of the oven-dry weight of the material distilled, are shown in Table 2.

TABLE 2.— *Yields of alcohol and acetic acid in percentages of oven-dry weight of material distilled.*

YIELD OF WOOD ALCOHOL (100 PER CENT).

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Beech	Indiana	1.95	1.79	2.04	1.87	1.99	Bark 1.25; Sapwood 1.97
Do	Pennsylvania	2.23	2.09		2.16		
Birch	Wisconsin	1.45	1.55	1.67	1.50	1.54	
Do	Pennsylvania	1.62	1.59		1.605		
Maple	Wisconsin	1.94	1.91	1.59	1.93	1.76	Bark 1.88
Do	Pennsylvania	1.94	1.78		1.86		
Red gum	Missouri	1.76	1.73		1.75		
Chestnut	New Jersey	.90	.87		.89		Limbs .96
Hickory	Indiana			2.08		2.08	
White oak	do	1.34	1.33	1.51	1.33	1.43	
Do	Arkansas	1.33	1.46		1.39		
Tupelo	Missouri	1.56	1.86		[1] 1.86		Limbs [1] 1.64

YIELD OF ACETIC ACID (100 PER CENT).

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.
Beech	Indiana	5.56	6.18	5.78	5.87	5.65	Bark 2.98; Sapwood 6.67
Do	Pennsylvania	5.77	6.21		5.99		
Birch	Wisconsin	6.71	6.88	6.62	6.80	6.68	
Do	Pennsylvania	6.19	6.10		6.15		
Maple	Wisconsin	5.42	5.11	5.58	5.24	5.49	Bark 3.15
Do	Pennsylvania	5.66	5.44		5.55		
Red gum	Missouri	5.70	5.23		5.46		
Chestnut	New Jersey	5.50	5.26		5.38		Limbs 6.42
Hickory	Indiana			5.05		5.05	
White oak	do	4.97	4.77	4.84	4.87	4.78	
Do	Arkansas	4.23	4.35		4.29		
Tupelo	Missouri	4.49	5.19		5.19		Limbs [1] 5.64

[1] Heartwood not included in average, since only one distillation was made on this material.

The yields of alcohol and acetic acid vary a great deal among the different species, more so for alcohol than for acetic acid. A given species may rank high in its yield of alcohol but low in its yield of acid. Thus chestnut, which gives the lowest yield of alcohol, is among the highest in yield of acid; and hickory, which is among the highest in alcohol yield, is among the lowest in acid yield.

The average yield from the beech, birch, and maple wood from Wisconsin and Indiana is somewhat higher for acid and considerably lower for alcohol than for the same species in Pennsylvania. This difference, when figured to commercial products—namely, 82 per cent alcohol and 80 per cent acetate of lime—amounts to about 10 per cent of the alcohol and 1½ per cent of the acetate of lime (see Table 4). The greatest differences are in the alcohol yield from beech and in the acid yield from birch. In the case of maple, the yields of both acid and alcohol are slightly higher from the Pennsylvania than from the Wisconsin wood. In contrast to these variances in absolute yield, the relative yield of the three species in either product does not change with the locality. The order of yield for alcohol is beech, maple, birch; for acid, birch, beech, maple. In the case of oak, the largest difference lies in the acid yield, the material from the more southern locality giving the lower yield. The yield of alcohol from wood cut in different States is very nearly the same, but if the runs on lumber are included the average is slightly higher for material from the northern localities.

VARIATION DUE TO FORM OF MATERIAL.

Although slabs with much bark are usually considered very poor material for distillation, the yields of alcohol and acetic acid from slabs having as high as 13 to 25 per cent bark by volume are in most cases only slightly lower, and in some cases even higher, than from heartwood. Distillation of beech bark showed that the higher yields of acid from beech slabs were not due to the bark, but to the very high yields of the sapwood (slabs without bark). These offset the low bark yields sufficiently to account for the fact that slabs with 13 per cent bark yielded more acid than the heartwood without bark. The same or higher yield of acid from the slabs of birch and tupelo and from the limbs of chestnut and tupelo is probably due to the same cause. The yields of alcohol from the sapwood of beech were practically the same as from the heartwood, and since the bark yields considerably less alcohol, the slabs with 13 per cent bark yielded less than the heartwood. Maple bark yielded very nearly as much alcohol as the heartwood, which accounts for the relatively high yields from the slabs.

CHARCOAL, TAR, AND GAS.

The yields of charcoal, tar, and gas are not included in Table 2, since they are influenced very much by the maximum temperatures of distillation and therefore are not comparable to the same extent as the alcohol and acetic-acid yields. Besides, these products are of indefinite composition, which further prevents comparison. There are some points of interest, however, in the relations between the yields of these products, and in Table 3 the average yields of alcohol, tar, and charcoal are shown, the species being arranged in order of the yields of alcohol.[1] The total tar yields follow almost the same order as the alcohol yields. The yields of charcoal, on the other hand, tend to follow the reverse order, but with more exceptions. The lowest yield of charcoal and the highest yields of alcohol and of tar are obtained from one species—hickory; while the highest yield of charcoal and the lowest yields of alcohol and of tar are also obtained from one species—chestnut.

TABLE 3.—*Average yields of alcohol, total tar, and charcoal from the heartwood of various species, in percentages of dry weight of material distilled.*

Species.	Alcohol.	Total tar.	Charcoal.	Species.	Alcohol.	Total tar.	Charcoal.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
Hickory	2.08	13.0	37.7	Tupelo	1.56	10.6	44.1
Beech	2.08	9.4	41.9	Birch	1.53	12.0	40.6
Maple	1.94	12.8	40.6	Oak	1.34	7.8	45.7
Red gum	1.76	11.7	38.6	Chestnut	.90	4.6	47.6

YIELDS PER CORD.

ALCOHOL AND ACETATE.

COMPARISON OF YIELDS.

Table 4 shows the same results as Table 2, but expressed in different units—the raw material in terms of gallons of 82 per cent wood alcohol and pounds of 80 per cent acetate of lime.

The yields from the various species on a cord basis are quite different from the yields on a unit weight basis; the heavier woods, such as hickory and oak, are advanced in relative position, and the lighter woods, such as chestnut and red gum, are reduced.

The average yield of alcohol from Indiana beech and Wisconsin birch and maple is 10.9 gallons per cord; the yield from these species from Pennsylvania is 11.51 gallons per cord. These figures represent the average yields obtained at commercial plants in these localities.[2] The average yield of acetate of lime from these two groups of woods, 319 pounds and 315 pounds per cord, respectively, is about 50 per cent higher than the average commercial yields. The yield from white oak from Arkansas of 9.2 gallons alcohol is very close to that being obtained in one commercial plant, and the acetate yield of 262 pounds per cord is, as in the case of the standard species, about 50 per cent higher than the commercial yield. The only ways in which the experimental distillations differed from commercial conditions were the low maximum temperatures and the short distance from the center of the charge to the heated surface of the retort. It is possible that these two conditions, resulting in a slow and well-controlled distillation, are sufficient to account for the higher yields.

[1] These averages do not include the yields from "lumber," since this material was usually very dry resulting in maximum temperatures much higher than the normal, giving yields of tar and charcoal not comparable with the rest of the runs.

[2] A corresponding difference between the Lake States and the Eastern States is also obtained commercially in the acetate yields, but this difference is not shown in the laboratory yields. It must be remembered, however, that these figures represent the average from equal proportions of the three standard species, while in actual practice one species may predominate.

In Table 5 are given the relative yields from the different forms and species, taking the average of the heartwood and lumber runs

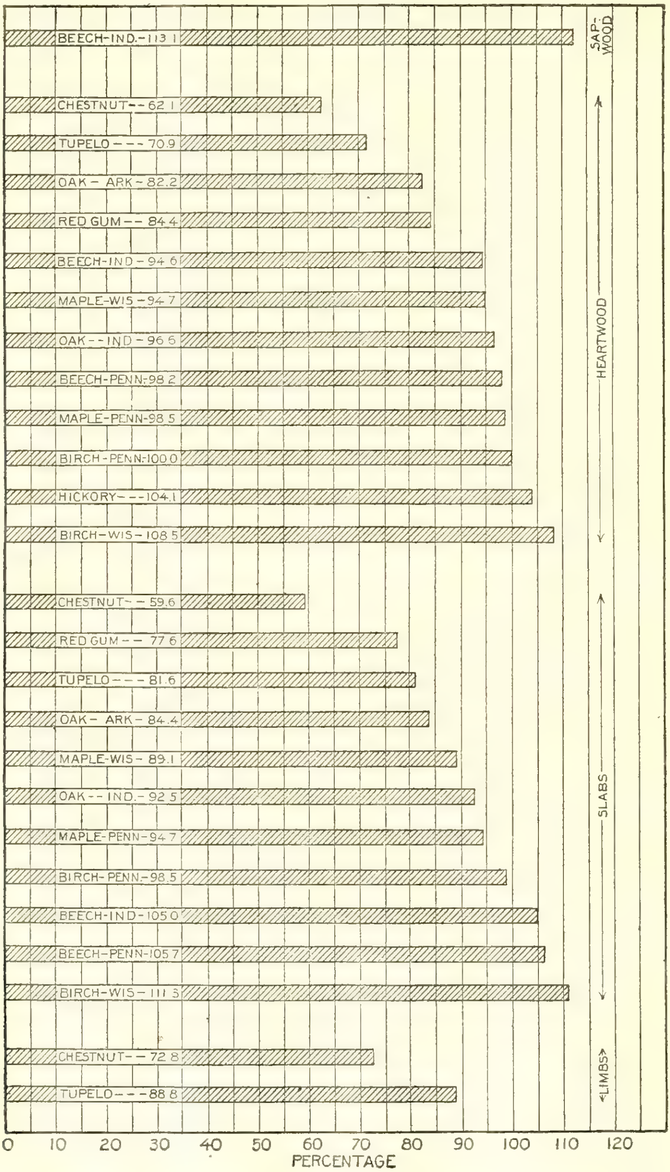

FIG. 2.—Relative yields of acetate of lime per cord. (Average yield from heartwood and lumber of beech, birch, and maple from Wisconsin=100 per cent.)

on beech, birch, and maple from Wisconsin as the standard (100 per cent). The same values are shown graphically in figures 2 and 3 for acetate and alcohol, respectively.

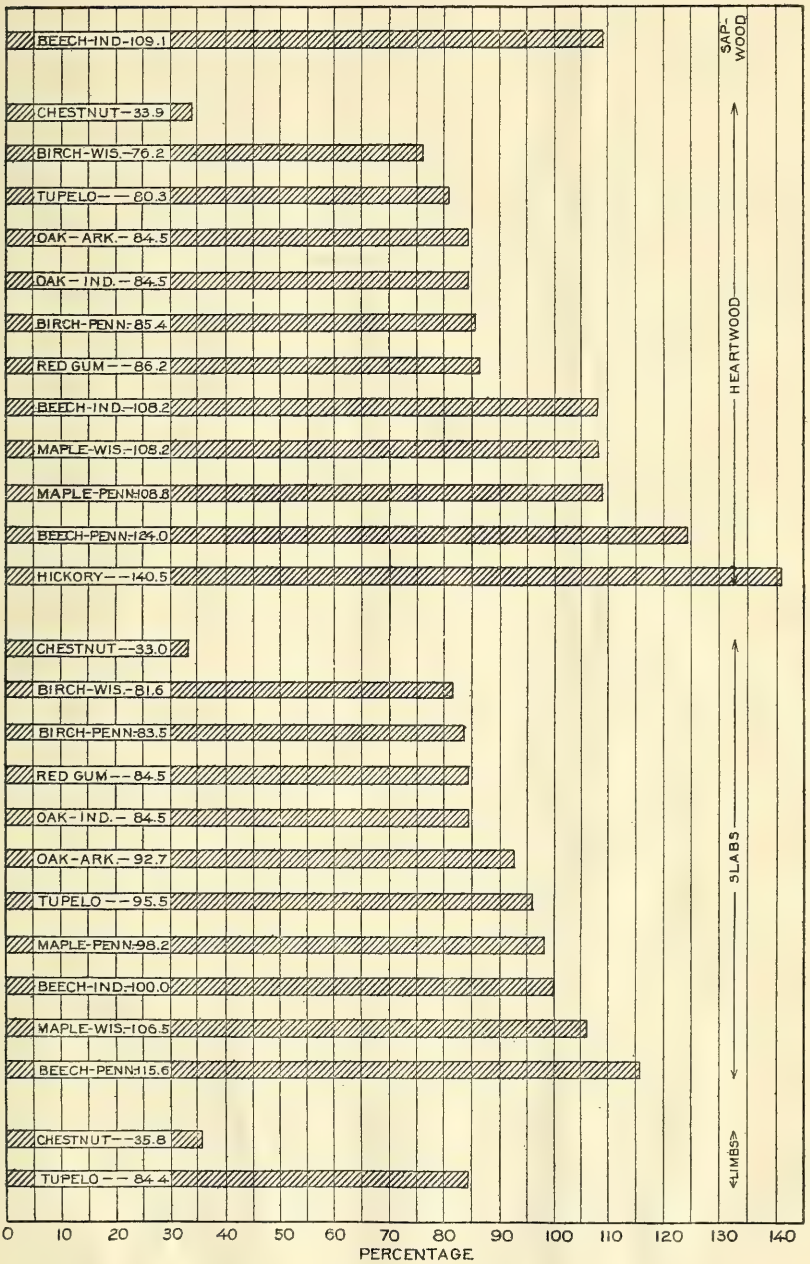

Fig. 3.—Relative yields of wood alcohol per cord of wood. (Average yield from heartwood and lumber of beech, birch, and maple from Wisconsin=100 per cent.)

TABLE 4.—*Yields of commercial alcohol and acetate from various species per cord of wood.*

YIELD OF WOOD ALCOHOL (82 PER CENT).

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.
		Gals.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*
Beech	Indiana	11.8	10.9	12.2	11.4	12.05	Sapwood... 11.9
Do	Pennsylvania	13.5	12.6	....	13.15	....	
Birch	Wisconsin	8.3	8.9	9.6	8.6	8.9	
Do	Pennsylvania	9.3	9.1	....	9.2	....	
Maple	Wisconsin	11.8	11.6	9.87	11.7	10.9	
Do	Pennsylvania	11.85	10.7	....	11.3	....	
Red gum	Missouri	9.4	9.2	....	9.3	....	
Chestnut	New Jersey	3.7	3.6	....	3.6	....	Limbs...... 3.9
Hickory	Indiana	....	....	15.3	....	....	
White oak	....do	9.2	9.2	10.4	9.2	9.9	
Do	Arkansas	9.2	10.1	....	9.65	....	
Tupelo	Missouri	[1] 8.75	10.4	....	9.1	....	Limbs..... 9.2

[1] Single unchecked determination.

YIELD OF ACETATE OF LIME (80 PER CENT).

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.	Weight per cord[1] (15 per cent moisture).
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Beech	Indiana	301	335	313	318	307	Sapwood... 361	3,785
Do	Pennsylvania	313	337	....	325	....	....	3,785
Birch	Wisconsin	346	355	341	350	343	....	3,600
Do	Pennsylvania	319	314	....	316	....	....	3,600
Maple	Wisconsin	301	284	310	293	305	....	3,875
Do	Pennsylvania	314	302	....	308	....	....	3,875
Red gum	Missouri	269	247	....	258	....	....	3,300
Chestnut	New Jersey	198	190	....	194	....	Limbs...... 232	2,520
Hickory	Indiana	....	....	332	....	332	....	4,590
White oak	....do	308	295	300	301	305	....	4,320
Do	Arkansas	262	269	....	265	....	....	4,320
Tupelo	Missouri	226	260	....	243	....	Limbs...... 283	3,510

[1] The weights per cord are derived as explained on p. 6.

TABLE 5.—*Relative yields of commercial alcohol and acetate per cord of wood of various species.*[1]

[Average yields [2] from heartwood and lumber of beech, birch, and maple from Wisconsin equals 100 per cent.]

Species.	Locality.	Yield of acetate of lime (80 per cent).			Yield of wood alcohol (82 per cent).		
		Heartwood.	Slab wood.	Other forms.	Heartwood.	Slab wood.	Other forms.
		Gals.	*Gals.*	*Gals.*	*Gals.*	*Gals.*	*Gals.*
Beech	Indiana	94.6	105.0	Sapwood. 113.1	108.2	100.0	Sapwood 109.1
Do	Pennsylvania	98.2	105.7	....	124.0	115.6	
Birch	Wisconsin	108.5	111.3	....	76.2	81.6	
Do	Pennsylvania	100.0	98.5	....	85.4	83.5	
Maple	Wisconsin	94.7	89.1	....	108.2	106.5	
Do	Pennsylvania	98.5	94.7	....	108.8	98.2	
Red gum	Missouri	84.4	77.6	....	86.2	84.5	
Chestnut	New Jersey	62.1	59.6	Limbs... 72.8	33.9	33.0	Limbs.. 35.8
Hickory	Indiana	104.1	....	....	140.5	....	
White oak	....do	96.6	92.5	....	84.5	84.5	
Do	Arkansas	82.2	84.4	....	84.5	92.7	
Tupelo	Missouri	70.9	81.6	Limbs... 88.8	80.3	95.5	Limbs.. 84.4

[1] The weights per cord are derived as explained on p. 6.
[2] Acetate of lime, 80 per cent, 319 pounds; alcohol, 82 per cent, 10.9 gallons.

COMPARISON OF VALUES.

The combined value of commercial alcohol and acetate of lime from the various forms of material per cord of wood of the various species is given in Table 6, which is computed from the yields given in Table 4. These values are according to the prevailing prices for 1911–13.[1]

In judging the value of the different forms and species for distillation, the yields under commercial conditions must be considered, and therefore the value of the acetate per cord of wood of different species is computed on a basis of two-thirds of the yields shown. The value of the alcohol is based on the experimental yields, since these are at most only slightly higher than average commercial yields. Tar and gas are not included in the computation of the value of products, because they are relatively unimportant and are commonly used as fuel at the plant. Charcoal is one of the valuable commercial products, but is not included because there are no definite data from which the values might be computed. The charcoal produced by the experimental method has not been subjected to temperatures as high as in commercial practice, and therefore contains more volatile matter. Although the relation between the yields obtained from different species in the experiments might be the same as between those obtained by commercial methods, there is no information on the quality of the charcoal from different species. Also, charcoal is usually sold by volume, and since no data are available on the weight per bushel for that produced from different species, the yields can not be computed to commercial units.

TABLE 6.—*Values of commercial alcohol and acetate per cord of wood of various species.*[1]

Species.	Locality.	Values of wood alcohol and acetate of lime during period 1911–13.[2]						
		Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Other forms.	Average lumber and heartwood.	Weight of cord,[3] (15 per cent moisture).
								Pounds.
Beech	Indiana	$8.08	$8.41	$8.38	$8.26	Sapwood, $9.10	$8.23	3,785
Do	Pennsylvania	8.72	8.89		8.81			3,785
Birch	Wisconsin	7.92	8.22	8.17	8.07		8.04	3,600
Do	Pennsylvania	7.73	7.59		7.66			3,600
Maple	Wisconsin	8.08	7.74	7.72	7.91		7.90	3,875
Do	Pennsylvania	8.31	7.80		8.06			3,875
Red gum	Missouri	6.92	6.50		6.71			3,300
Chestnut	New Jersey	4.28	4.11		4.19	Limbs, $4.89		2,520
Hickory	Indiana			9.51			9.51	4,590
Oak	do	7.52	7.30	7.70	7.41		7.61	4,320
Do	Arkansas	6.76	7.08		6.92			4,320
Tupelo	Missouri	[4] 6.04	7.03		6.59	Limbs, $7.10		3,510

[1] The market price of crude alcohol is fairly stable, but acetate of lime fluctuates considerably from time to time. For this reason the relative value of the different species, from the standpoint of value of products, may vary from the calculations indicated.

[2] The weights per cord are derived as explained on p. —.

[3] At 26 cents per gallon for alcohol and $2.50 per hundredweight for acetate of lime. The acetate is computed from two-thirds the yields given in Table 4.

[4] One determination only.

TABLE 7.—*Relative values of commercial alcohol and acetate per cord of wood of various species.*[1]

[Average value of yields from heartwood and lumber of beech, birch, and maple from Wisconsin ($8.06) equals 100 per cent.]

Species.	Locality.	Heartwood.	Slabs.	Heartwood and lumber.	Mean heartwood and slabs.	Sapwood.	Limbs.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Beech	Indiana	100.2	104.2	102.1	102.5	113.0	
Do	Pennsylvania	108.1	110.2		109.2		
Birch	Wisconsin	98.4	102.0	97.7	100.1		
Do	Pennsylvania	96.0	95.5		95.8		
Maple	Wisconsin	100.2	96.0	95.8	98.1		
Do	Pennsylvania	103.0	97.0		100.0		
Red gum	Missouri	86.0	80.7		83.3		
Chestnut	New Jersey	53.2	51.0		52.1		60.7
Hickory	Indiana			118.0			
White oak	do	93.3	90.7	94.5	92.0		
Do	Arkansas	83.9	88.0		85.9		
Tupelo	Missouri	75.0	87.2		81.8		88.1

[1] The weights per cord are derived as explained on p. 6.

Assuming that the value of the charcoal and the cost of plant operation per cord of wood is the same for all species, the differences in the value of the alcohol and acetate produced by the various woods represent the differences in the value of these woods for distillation purposes.[1] The average value of the alcohol and acetate yields from Indiana beech and Wisconsin birch and maple heartwood is $8.06 per cord. The values of these products from the heartwood of chestnut, red gum, tupelo (slabs), and southern and northern oak, are less than this amount by $3.78, $1.14, $1.03, $1.30, and $0.54, respectively; from hickory (factory waste) the products are $1.55 greater in value. The average price paid is only about $3.50 per cord, and consequently the use of chestnut for this purpose is out of the question. Oak, tupelo, and red gum, under favorable conditions of supply and cost, might be used profitably, while hickory should command a very good price for this purpose. Since these deductions are based on the value of the chemical products they apply less strongly in case of plants making only a partial recovery of these products.

The value of alcohol and acetate from the different forms and species as given in Table 6 are compared in Table 7 by means of a standard value. This value is $8.06, being the average value of beech (from Indiana), birch, and maple heartwood (from Wisconsin). This standard is taken as 100 per cent and the other values are ranked accordingly.

[1] The assumption in regard to the cost of operation will undoubtedly hold so far as the destructive distillation of the wood is concerned. However, the cost of the refining operations is approximately proportionate to the amount of crude pyroligneous acid produced; although this is variable, it bears some relation to the yield of refined products. The large amount of crude pyroligneous acid per cord of hickory would tend to increase the refining cost per cord of wood; likewise the low yields of crude pyroligneous acid from chestnut, tupelo, and red gum would tend to lower the cost of these woods. Therefore, the assumption made is not entirely correct, but the differences are not great enough to affect seriously the conclusions.

The value of the two products (alcohol and acetate) from hickory is 18 per cent greater than the standard chosen for the comparison. Of the other species, oak from Indiana is the only one which falls above 90 per cent; with all the others, except chestnut, the average yield from heartwood and slab wood is above 80 per cent.

Of equal interest to these relative values based upon species are the relative values of the different forms of wood from the same species. These relations are shown in Table 8, in which the value of heartwood in each case is taken as 100 per cent. A number of species show a higher value for slabs than for heartwood. The slabs of Indiana beech, Wisconsin birch, Pennsylvania beech, and Arkansas oak are from 2 to 5 per cent higher that the heartwood, while the limbs of the two species tested, chestnut and tupelo, are about 15 per cent higher than heartwood. These results are based upon equal weights of the several forms of material compared.

TABLE 8.—*Relative values of commercial alcohol and acetate from equal weights of various forms of material.*

[Heartwood=100 per cent.]

Species.	Locality.	Heartwood.	Slab wood.	Sapwood.	Limbs.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Beech	Indiana	100	104.0	112.5	
Do	Pennsylvania	100	102.0		
Birch	Wisconsin	100	103.8		
Do	Pennsylvania	100	98.2		
Maple	Wisconsin	100	95.8		
Do	Pennsylvania	100	93.9		
Red gum	Missouri	100	94.0		
Chestnut	New Jersey	100	96.0		114.2
Hickory	Indiana	100			
White oak	do	100	97.2		
Do	Arkansas	100	104.8		
Tupelo	Missouri	100	116.5		117.5

PYROLIGNEOUS ACID, TAR, AND CHARCOAL.

The average yields of pyroligneous acid, tar, and charcoal from the various forms of material, expressed in pounds per cord for each species, are given in Table 9. Although the yields of these products, especially of the last two, are directly affected by the maximum temperatures of distillation, and are therefore not as accurate as the alcohol and acetate yields, some conclusions of interest can be drawn from them. The yields of pyroligneous acid are of interest mainly in connection with the cost of refining the products from a cord of wood. (See footnote on p. 14.)

The average commercial yield of charcoal from a cord of beech, birch, and maple is about 50 bushels or (at 20 pounds, the usual weight per bushel) 1,000 pounds; the average yield from the heartwood of the three species by the experimental method is 1,378 pounds per cord. This large difference is probably due chiefly to the low maximum temperatures of distillation, resulting in a charcoal with a high amount of volatile matter. Charcoal of this composition would probably be satisfactory as a fuel for domestic use, but where high carbon content or high crushing strength is required it might not be suitable.

The yields of tar are also somewhat higher than those usually obtained in practice, and this can not be explained entirely by the low maximum temperature of distillation, since further distillation of the charcoal at higher temperatures gave increased production of tar. (See p. 4.) It is probable, however, that under the experimental conditions of distillation there was less tar decomposed into gas and coke than under commercial conditions where part of the tar would be subjected to considerably higher temperatures after formation.

TABLE 9.—*Average yields per cord of pyroligneous acid, charcoal, and tar from various species.*[1]

PYROLIGNEOUS ACID (MINUS MOISTURE).

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.	
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*
Beech	Indiana	1,062	1,165	1,119	1,113	1,085	Sapwood	1,149
Do	Pennsylvania	1,180	1,158	....	1,169	....		
Birch	Wisconsin	1,152	1,159	1,220	1,156	1,167		
Do	Pennsylvania	1,249	1,135	....	1,192	....		
Maple	Wisconsin	1,120	1,061	1,207	1,145	1,157		
Do	Pennsylvania	1,125	1,164	....	1,145	....		
Red gum	Missouri	1,098	917	....	1,005	....		
Chestnut	New Jersey	790	644	....	716	....	Limbs	714
Hickory	Indiana	....	....	1,495	....	1,495		
White oak	do	1,230	1,170	1,275	1,209	1,156		
Do	Arkansas	1,155	1,120	....	1,135	....		
Tupelo	Missouri	1,081	1,065	....	1,073	....	Limbs	1,049

CHARCOAL.

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.	
Beech	Indiana	1,417	1,297	1,385	1,357	1,403	Sapwood	1,470
Do	Pennsylvania	1,335	1,383	....	1,359	....		
Birch	Wisconsin	1,315	1,284	1,286	1,300	1,303		
Do	Pennsylvania	1,228	1,300	....	1,265	....		
Maple	Wisconsin	1,341	1,515	1,348	1,344	1,430		
Do	Pennsylvania	1,352	1,268	....	1,310	....		
Red gum	Missouri	1,058	1,360	....	1,210	....		
Chestnut	New Jersey	1,041	1,160	....	1,102	....	Limbs	1,061
Hickory	Indiana	....	....	1,500	....	1,500		
White oak	do	1,858	1,892	1,625	1,875	1,715		
Do	Arkansas	1,580	1,734	....	1,654	....		
Tupelo	Missouri	1,400	1,405	....	1,402	....	Limbs	1,320

TOTAL TAR.

Species.	Locality.	Heartwood.	Slab wood.	Lumber.	Mean heartwood and slab wood.	Average lumber and heartwood.	Other forms.	
Beech	Indiana	319	349	342	332	329	Sapwood	250
Do	Pennsylvania	299	359	....	329	....		
Birch	Wisconsin	325	285	338	307	330		
Do	Pennsylvania	426	347	....	385	....		
Maple	Wisconsin	418	310	500	450	360		
Do	Pennsylvania	422	416	....	418	....		
Red gum	Missouri	336	215	....	276	....		
Chestnut	New Jersey	102	80	....	91	....	Limbs	173
Hickory	Indiana	....	....	519	....	519		
White oak	do	237	173	331	203	285		
Do	Arkansas	319	327	....	338	....		
Tupelo	Missouri	348	370	....	364	....	Limbs	447

[1] The weights per cord were derived as explained on p. 6.

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Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
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OPERATING COSTS OF A WELL-ESTABLISHED NEW YORK APPLE ORCHARD.[1]

By G. H. Miller, *Assistant, Office of Farm Management.*

INTRODUCTION.

It is not primarily the purpose of this bulletin to present data which actually show the cost of operating a mature orchard, but rather to suggest a plan of cost accounting for orchard operations. This will be useful to fruit growers who wish to determine the cost of fruit production.

Probably in no branch of farming have greater recent advances been made than in fruit growing. The growing of the apple is one of the most highly specialized branches of agriculture. It is a business which requires scientific knowledge, skill, and the greatest care to make it a success. Many investors have entered the field, and many of the older growers are realizing profits. Thus spurred on by stories of fabulous returns, millions of trees have been set in the last decade. It is probably safe to say that few know the cost of growing this fruit. It is certain that there is a scarcity of accurate data published on this problem.

The method of cost accounting is discussed through the presentation of two years' data obtained by the Office of Farm Management through cooperation with Mr. H. E. Wellman, a progressive fruit grower in Orleans County, N. Y. Detailed records of all daily labor and financial transactions were kept, including complete inventories and accurate surveys of all crops, as well as all necessary information to determine not only the costs of the apple enterprise, but also the cost of the entire farm business. It should be carefully noted that the data presented in this bulletin are costs based on the annual expense factors incident to the maintenance and operation of a well-cared-for mature orchard. No attempt is made to establish a normal for the different items entering into the cost of growing

[1] Acknowledgment is due to Mr. J. S. Ball for aid in the compilation of the data presented and to Mr. H. E. Wellman, through whose cooperation this work was made possible.

NOTE.—This bulletin contains data on the cost of producing apples on a mature orchard operated in connection with a general farm in western New York. The information is applicable to all similar operations.

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apples over the entire country, for to do that would require a much more extended study.

No figures are available from which to determine the cost of planting and caring for this orchard up to the time it began to return

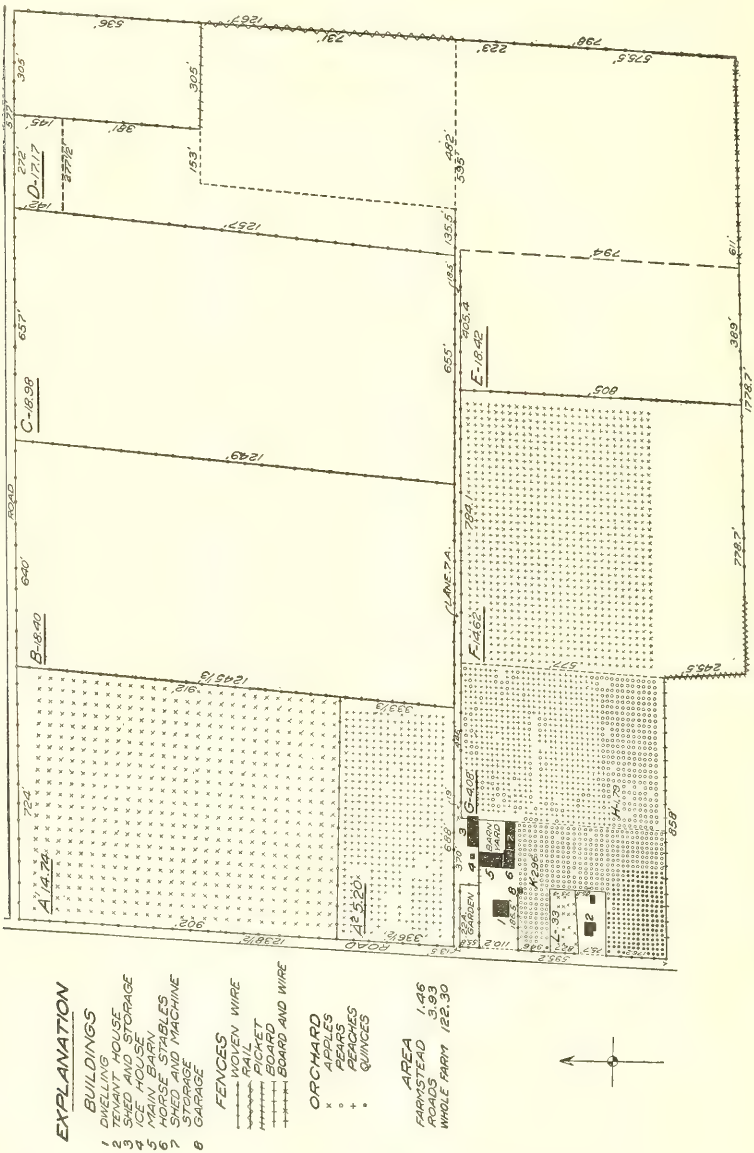

FIG. 1.—Diagram of the Wellman farm showing the arrangement of the fields and the location of the orchards.

profitable crops. No attempts have been made at estimating the profit or loss that may result from this area during the declining years of the orchard, and no loss factors incident to crop failure such as occur in the life of every orchard enterprise appear here. It must be remembered that these records cover expense items only during two years of the life of the orchard and do not show the full cost of apple production, even in a region of high potential possibilities for this industry.

The farm under consideration is situated in the northeastern part of Orleans County, 1 mile south of Lake Ontario and 1½ miles from the shipping point.

The farm, a diagram of which is shown as figure 1, consists of 122.3 acres of tillable land, well drained. The soil varies from a medium clay loam to a stiff clay. Of this 122.3 acres, 39 acres, or approximately 37 per cent of the crop area, are in fruit.

Table I shows the relation of the fruit and general crops on the farm as a unit.

TABLE I.—*Summary of crop areas on the Wellman farm for 1911 and 1912.*

Crops.	Proportion of crop area in—			
	1911	1912	1911	1912
Orchard fruits:	*Acres.*	*Acres.*	*Per cent.*	*Per cent.*
Apples in bearing	14.74	14.74	14.1	14.1
Peaches in bearing	7.85	7.85	7.5	7.5
Pears in bearing	3.95	3.95	3.8	3.8
Quinces in bearing	.80	.80	.7	.7
Total bearing fruit	27.34	27.34	26.1	26.1
Apples and peaches, nonbearing	9.92	9.92	9.5	9.5
Apples, nonbearing	1.26	1.26	1.2	1.2
Quinces, nonbearing	4.70	....	4.5	....
Total nonbearing fruit	15.88	11.18	15.2	10.7
Total fruit	43.22	38.52	41.3	36.8
General farm crops:				
Beans	11.01	17.28	10.5	16.6
Wheat	18.04	18.95	17.3	18.0
Hay	19.00	18.98	18.1	18.1
Corn	4.70	4.67	4.5	4.5
Potatoes	.80	.83	.8	.8
Oats	7.90	5.47	7.5	5.2
Total general farm crops	61.45	66.18	58.7	63.2
Recapitulation:				
Area in fruit	43.22	38.52	41.3	36.8
Area in general farm crops	61.45	66.18	58.7	63.2
Total	104.67	104.70	100	100
Pasture, roads, and farmstead	17.63	17.60	....	....
Total farm area	122.30	122.30	....	....

MANAGEMENT OF THE FARM.

The farm studied is a typical western New York farm on which fruit is the foremost of the enterprises. Of the total area, 50 per cent is devoted to general farm crops other than fruit. It is the plan to raise enough hay, oats, and corn for feed. Potatoes are raised only for home use. Besides fruit, wheat and beans are the cash crops. Each year 20 or 30 sheep are kept and pastured during the summer. Lambs are raised and fattened during the early spring months. Six horses are kept for work and one for family use. One or two colts are raised each year.

The organization of any farm of this type will have more or less bearing on the method of management of the orchard and will therefore have its influence on the cost of producing fruit. There will be more or less variation, whether it is a general farm with fruit as one of the enterprises or a specialized fruit farm.

The apple orchard, consisting of 14.74 acres, is situated in the northwestern part of the farm. There are 527 trees of bearing age,

FIG. 2.—View in the Wellman orchard, showing the size and shape of the trees.

45 to 65 years old, consisting mainly of Baldwins and Rhode Island Greenings.

The soil here is a medium clay loam about 10 inches deep, with a subsoil of heavy clay. The orchard has a slight northerly slope, and the drainage is good.

HISTORY OF THE ORCHARD.

In 1864, at the time Mr. I. E. Wellman took possession of the farm, there were 100 Baldwin trees about 20 years old. In 1866, 150 Baldwin and Fall Pippin trees were set out, and in 1871 the remainder of the orchard was set to Baldwin and Rhode Island Greening trees. These trees were set 33 by 33 feet on the square. The orchard as it now appears is shown in figure 2.

EARLY TREATMENT OF THE ORCHARD.

Up to the time that the orchard came into bearing it was cropped with a rotation of beans, barley, wheat, and clover. When the trees came into bearing, the orchard was allowed to remain in sod and was used mainly for a cattle and sheep pasture. Owing to the low returns, orchards in western New York were cut down to a great extent about 1893, and at that time land on which apple trees stood was assessed for little or nothing. But on this specific farm in 1894 greater care was taken to make the orchard produce more, and in 1896 it bore its heaviest crop, like many orchards in the region. In 1897 the orchard was plowed and cultivated. This was the beginning of an organized effort to make the orchard profitable. Since that date greater care in pruning, spraying, and cultivation has been given.

CULTURE SINCE 1907.

In the spring of 1907 the entire orchard was plowed 3½ inches deep. During that season it was harrowed five times, and a cover crop of clover, 6 quarts of seed to the acre, was sown the latter part of July. In 1908 the orchard was left in sod. In 1909 a double-action disk was used to break up the sod. This was followed by a spring-tooth harrow during the summer, and in the month of July the orchard was again sown to clover. It was mowed in 1910, and in 1911 the soil was plowed away from the trees. During the summer the orchard was cultivated five times and sown to clover in the latter part of July.

In 1912 there was an excellent clover sod, but during the month of August the army worms appeared in great numbers, eating the clover to the ground and giving the remaining cover the appearance of having been swept by fire.

RATES PAID FOR LABOR.

The rates of labor used in showing the costs of the orchard operations are the same as those of the other enterprises on the farm, such as the growing of beans, wheat, and hay. The cost per hour of man labor was 17.9 cents, and the cost per hour of horse labor was 15.3 cents. These rates represent the total cost of paid labor plus the value of board and privileges. The proprietor's labor was considered at the same rate as that of the regular workmen on the farm.

In the case of horses, a cost of $10 per month, or $120 a year, was used. This amount, divided by the total number of hours worked by the horses, gave an hourly cost of 15.3 cents. The rate of both man and horse labor was lessened by reason of the general farm crops, which utilized the labor when not needed for the fruit.

LABOR COSTS FOR VARIOUS OPERATIONS.

Three cost factors present themselves in any business enterprise. In this bulletin these are termed labor, cash, and fixed costs.

In considering the labor requirements in the production of fruit, the following questions present themselves: What operations make the total labor in the production of marketable apples? What factors influence the cost of these operations? What records should be kept by the grower so that he may at any time know the cost of a given operation and at the close of any season know the total cost of any and all operations?

In the management of commercial orchards there are operations which must be performed and which are essential for the production of marketable fruit. These operations will be discussed in the order of their occurrence in the western New York apple belt.

Detailed labor costs for the Wellman farm, taken during 1911 and 1912, are given in Table II.

TABLE II.—*Labor costs on the 14.74-acre Wellman apple orchard, containing 527 trees, for 1911 and 1912.*

Operations.	Dates.	Total hours.		Labor cost.			
		Man.[1]	Horse.[2]	Total.	Per acre.	Per tree.	Per barrel.
	1911.						
Pruning	Mar. 11 to Apr. 17	137		$24.52	$1.663	$0.046	$0.026
Removing brush	Apr. 10 to 26	27½	26	8.90	.604	.017	.009
Mixing lime and sulphur		8		1.43	.097	.003	.002
First spraying	Apr. 25 to May 2	49¼	38½	14.70	.998	.028	.016
Second spraying	May 12 to 13	45	30	12.65	.859	.024	.014
Third spraying	May 23 to 26	48½	48	16.03	1.088	.032	.017
Plowing	June 18 to 27	101¾	193½	47.81	3.243	.091	.051
Rolling	May 29 to June 7	10½	21	5.09	.344	.010	.006
First harrowing [3]	June 7 to 8	30½	61	14.79	1.004	.028	.016
Second harrowing	June 19 to 22	12¼	24½	5.94	.403	.011	.006
Third harrowing	June 30 to July 22	10	20	4.85	.329	.009	.005
Fourth spraying	July 20 to 21	24	24	7.97	.541	.015	.009
Sowing cover crop	July 22 to 24	10½		1.88	.128	.004	.002
Fourth harrowing	July 22 to 25	24¾	49½	12.01	.814	.023	.013
Picking apples	Aug. 31 to Oct. 19	765½		137.03	9.297	.260	.146
Picking up apples	Sept. 21 to Oct. 22	100¾		18.04	1.224	.034	.019
Packing apples	Aug. 31 to Nov. 3	418½		74.91	5.082	.140	.080
Marketing apples		234½	355½	96.36	6.536	.183	.102
Total for year		2,058¾	891½	504.91	34.254	.958	.539
	1912.						
Pruning	Dec. 21 (1911) to Apr. 26	229¼		41.03	2.784	.078	.019
Removing brush	Apr. 4 to May 3	74¼	60½	22.55	1.530	.043	.011
First spraying	May 3 to 4	55½	36	15.44	1.048	.029	.007
Second spraying	May 13 to 14	45½	30	12.73	.864	.024	.006
Third spraying	May 31 to June 6	80	54	22.58	1.532	.043	.011
Cutting clover	June 25 to July 11	13	26	6.31	.428	.012	.003
Cutting clover (with scythe)	June 28 to July 11	11		1.97	.133	.004	.001
Fourth spraying	Aug. 6 to 13	67¾	70	22.84	1.550	.043	.011
Thinning apples	Aug. 7 to 13	34		6.09	.413	.012	.003
Cutting blight	Aug. 16 to 29	22		3.94	.267	.007	.002
Picking apples	Aug. 26 to Oct. 31	239					
Contract picking	Oct. 9 to 31	553¾					
Total picking		792¾		319.48	21.674	.606	.152
Packing apples	Aug. 28 to Nov. 21	959		171.66	11.645	.325	.081
Hauling apples to barn	Sept. 28 to Oct. 31	137¾	124½	43.71	2.965	.083	.021
Marketing barreled apples	Aug. 26 to Nov. 21	193¾	383	93.28	6.329	.177	.044
Marketing driers	Oct. 2 to Dec. 4	84¼	168½	40.86	2.772	.077	.019
Picking up apples	Oct. 31 to Dec. 3	125½		22.46	1.524	.043	.011
Equipment to and from orchard.		4	8	1.94	.132	.004	.001
Inspection		9½		1.70	.115	.003	.001
Superintendence		34		6.09	.413	.012	.003
Total for year		3,062¾	960½	856.66	58.118	1.625	.407

[1] Man-hour rate, 17.9 cents.
[2] Horse-hour rate, 15.3 cents.
[3] Ground harrowed over twice. A 3-section spike-tooth harrow was used first, followed by a spring-tooth drag.

PRUNING.

Pruning is done during the dormant season, i. e., in the winter and early spring, when weather conditions are favorable. Many factors have their influence on the cost of this operation. The most important of these are the variety, age, and size of the trees, their characteristic growth, physical condition, distance apart, the style of pruning adopted by the grower, and, lastly, of greatest importance is the expertness of the operator.

In the orchard considered, between 20 and 25 trees are trimmed in a 10-hour day. Attention is annually given to each tree, which is pruned for an open head and cut well back, so that there will be sufficient space for sunlight and air. All dead wood and interfering branches are removed. It is the practice to thin out along the main branches rather than to cut out the large limbs. These large limbs, when cut, are trimmed up in the orchard and hauled to the house for firewood. In all cases, care is taken to prune so that the spray material may be thoroughly applied and picking may be done to the best advantage. The cost of pruning in this orchard in 1912 was 8 cents per tree.

SPRAYING.

Most western New York apple growers spray at least three times. Some spray as many as six times.

The gasoline power sprayer is most commonly used among the growers in this section, although hand outfits and a few steam engines are now and then found in use. A complete up-to-date gasoline engine, pump, tank, and truck cost from $200 to $350, depending upon the make and the horsepower of the engine. The cost of the operation will vary each year, being influenced largely by the number of sprayings.

The first application of spray is usually made when the trees are dormant, a second when the buds are pink, a third at the time the petals fall, and a fourth the latter part of July or the first part of August.

Numerous factors influence the cost of spraying. The variety and size of the trees and their distance apart have an influence on the time required for the spraying operation.

The amount of spray material used, as well as the thoroughness with which it is applied, depends upon whether the trees are dormant or partly or wholly in foliage. The condition and kind of material used will also affect the amount of labor needed.

Insect pests and diseases are sometimes more prevalent in one season than in another, and often some orchards are affected while others are not. The size and expertness of the crew used in spraying are factors to be carefully considered. The kind of spray outfit, together with its accessories, affects the cost of the operation. The efficiency of an outfit can be increased by the use of horses which are accustomed to the hauling of a sprayer. Long distance from water and spray materials causes the loss of considerable time, which could often be remedied with practically little outlay.

Figure 3 shows a spraying crew at work in the Wellman orchard.

Table III gives a summary of the spraying costs per acre, per tree, and per barrel of marketable fruit. In 1911 and in 1912 the orchard was sprayed four times. The first spraying was done at the time the fruit buds were showing a little green color, the second time when the fruit buds were pink, the third after two-thirds of the petals had

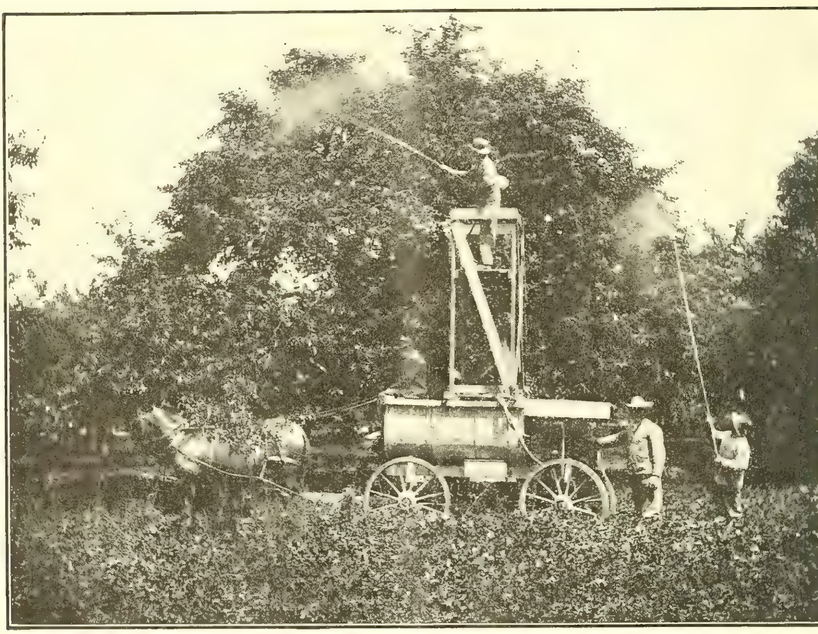

FIG. 3.—Power sprayer and crew. Two or three men are ordinarily used on the Wellman farm.

fallen, and the fourth the latter part of July in 1911 and the first part of August in 1912. If the same quantity of material were used and the same care taken each year, the time required for the operation would be nearly the same year after year. Referring to the first spraying in 1911 and 1912 (Table III), the cost of spraying would have been about the same if it had not been for the increased cost of spray materials. It is true that there was an increase in the amount of labor, due to the necessity of more thorough spraying for the control of the green aphids, but had this not been required the costs per acre of the 1911 and 1912 sprayings would have been approximately the same.

In the third and fourth sprayings of 1911 only the trees which blossomed were sprayed. This partly accounts for the lessened cost at those times.

TABLE III.—*Cost of spraying the 14.74-acre Wellman apple orchard, containing 527 trees from 45 to 60 years of age, in 1911 and 1912.*

Year and operation.	Hours per acre.		Cost per acre.			Cost of both material and labor.	
	Man.	Horse.	Labor.	Material.	Total.	Per tree.	Per barrel.
1911.							
First spraying	3.34	2.61	$0.998	$1.686	$2.684	$0.075	$0.042
Second spraying	3.05	2.03	.859	1.020	1.879	.053	.030
Third spraying	3.29	3.26	1.088	.765	1.853	.053	.029
Fourth spraying	1.63	1.63	.541	.358	.899	.025	.015
Total for season	11.31	9.53	3.486	3.829	7.315	.206	.116
1912.							
First spraying	3.76	2.44	1.048	.929	1.977	.055	.013
Second spraying	3.09	2.03	.864	.988	1.852	.052	.013
Third spraying	5.43	3.66	1.532	1.182	2.714	.076	.019
Fourth spraying	4.59	4.75	1.550	1.129	2.676	.074	.019
Total for season	16.87	12.88	4.994	4.228	9.219	.257	.064

TILLAGE.

There are many systems of orchard management in the apple belt of western New York. In the management of the Wellman orchard it has been the practice to plow 3½ to 4 inches deep in the spring. The ground is tilled during the season, and in the latter part of the summer a cover crop is sowed, the orchard remaining in sod the following year. With this plan of management the orchard is in sod every other year.

In 1911 this orchard was plowed. On the average, 1.5 acres were plowed each 10-hour day at a cost of $3.24 per acre. The depth of plowing, width of furrow, stiffness of sod, and the type of soil will influence the time required for this operation. Many times a single-horse plow is required to plow away from the trees. During the season the orchard was rolled once and harrowed five times. A cover crop was then sowed and the orchard again harrowed. The total labor cost of tillage was $6.26 per acre.

Figured on the basis of the yield in 1912, if the orchard had been plowed and worked during that year as in 1911 there would have been an increase of 4 cents per barrel in the labor cost. In addition, the cost of the cover crop would have been 2 cents per barrel, making a total increase of 6 cents per barrel in 1912.

If the plowing had been done in 1912, it would not have necessitated cutting the clover that year. This is a minor cost and would make a difference of less than 1 cent per barrel. In the late summer of 1911, the year the orchard was plowed, a cover crop of oats, clover, and cowhorn turnips was sowed. There was an excellent growth of clover, and the latter part of the following June it was cut. Considering the total acreage of the orchard, only about one-half of it was cut with the mower, as it was impossible to get near the trees with the machine. It was the original plan to form a mulch with this clover and the crop which might have followed, but on account of the destructive work of the army worms this was not possible.

The exact proportion of bearing apple orchard and tillable cropping land which would make the use of labor most efficient is not known. It may not be possible to arrive at such a figure, but it is worth being considered by every grower of fruit.

A very important question arises in this connection: Can the specializing fruit grower produce, handle, and market his fruit for less than the general farmer who makes the growing of the apple one of his farm enterprises?

HANDLING THE CROP.

The handling of the apple crop in the apple belt of western New York is a serious problem with many growers. Labor requires a high wage, and at times it is difficult to get efficient help. Some growers near the cities are able to get a little experienced help at harvesting time. Tramp labor often proves efficient, and many growers depend upon it.

The men with large bearing orchards are most seriously affected. The men on the general farms have some advantages over those on specialized fruit farms. On the general farms labor is needed the entire year, and this labor is often sufficient for the apple harvest.

PICKING.

The method adopted in picking apples depends to some extent on the size of the crop. The cost of the operation is influenced by many factors, of which the expertness of the picker is perhaps the greatest. The variety and quality of the fruit, the time of picking, the quantity of fruit on the tree, the shape and height of the tree, and the equipment used in picking the fruit are other factors which materially affect the cost.

In 1911 regular labor and a small amount of extra labor were used to pick the marketable crop of 937 barrels. This was done at a cost of 15 cents per barrel. In 1912 the early apples, 284 barrels, together with 108 barrels of Baldwins, were picked by regular labor and a small amount of extra labor at a cost of 11 cents per barrel.

The marketable barreled Baldwin crop was picked by contract labor at a cost of 16 cents per barrel.

During the season 30 Baldwin trees were thinned. About half the fruit was removed when the size of walnuts at a cost of 20 cents per tree. At harvest time the same quantity of marketable apples was picked from these trees as from 30 Baldwin trees which were not thinned.

Table IV shows the number of barrels of Baldwin apples picked by contract labor in 1912, together with the cost of picking.

TABLE IV.—*Number of barrels of Baldwin apples and cost per barrel of picking by contract labor on the Wellman orchard in 1912.*

Pickers.	Rate to picker per barrel.	Number of barrels.[1]	Cost of picking.			Average number of barrels picked per day.	Cost per barrel.
			Cash.	Board.	Total.		
G. L.	$0.11	321					
Do.	.12	123	$50.07	$13.50	$63.57	31.5	$0.143
B. W.	.12	74	8.88	2.25	11.13	24.7	.15
M. R.	.11	210					
Do.	.12	84	33.18	14.25	47.43	18.1	.161
A. R.	.125	383					
Do.	.135	144	67.32	3.80	71.12	31.5	.135
T. S.	.11	45	4.95	2.25	7.20	21.4	.16
H. L.	.11	105	11.55	5.25	16.80	16.4	.16
R. K.	.12	165	19.80	3.00	22.80	41.3	.138
C. M.	.12	225	27.00	4.20	31.20	28	.139
C.	.10	32	3.20	2.25	5.45	10.7	.17
Total		1,911	225.95	50.75	276.70		
Average	.118						.145

[1] Of 1,911 barrels picked by contract labor, 1,712 barrels were marketable. The average cost of picking the marketable barreled apples was 16 cents per barrel.

PACKING.

In 1911 the packing time was nearly equally divided between orchard and barn. The average cost of packing was 8 cents per barrel.

In 1912 the average cost of packing apples was 9 cents per barrel. An account was taken of the time actually spent in packing apples in the orchard and in the barn in 1912. There were 854 barrels packed in the orchard at a cost of 7.7 cents per barrel, while 1,250 barrels were packed in the barn at a cost of 13.2 cents per barrel. In considering the cost of packing in the barn the actual time charge would amount to 9.7 cents per barrel. The cost of hauling these apples to the barn was 3.5 cents per barrel, which is part of the packing cost.

MARKETING.

In 1911 the labor of hauling the dried and the barreled apples was combined, and therefore the cost of hauling the barreled apples to market can not be ascertained for that year. In 1912, however, the apples were hauled 1.5 miles to storage, at a cost of 36 cents per ton per mile. The cost per barrel per mile was 3 cents.

On return trips from storage the driver passed near the barn, taking a load of empty barrels to the orchard. The time required for this operation was small and considered part of the marketing cost. At noon, on the way to dinner, a load of unsorted apples was usually hauled to the barn. Generally a load was hauled also at the close of the day. When the weather would not permit outside work, the apples were packed in the barn. This cost was considered under packing. Even though the cost of packing in the barn was higher, this was doubtless more than offset, as the help was able to work during bad weather.

The principal labor operations which were performed on this particular farm in order to produce marketable fruit have been described. There are many minor factors which would influence the cost of these operations. Definite figures which could be used universally can not be given. Each farm is a unit, and the several enterprises are managed differently on each farm. The figures presented are suggestive and illustrate the method used in arriving at the total labor cost of producing a marketable barrel of apples on the Wellman farm during the two years specified.

A summary is given in Table V of (1) the cost of operations up to picking time and (2) the cost of handling the crop. Although the 1912 crop was more than double that of 1911, the cost of handling it was only one-half a cent less per barrel. Up to picking time in both years the operating cost per tree was about the same.

TABLE V.—*Summary of labor costs on the 14.74-acre Wellman apple orchard, containing 527 trees, in 1911 and 1912.*

Item of cost.	1911		1912	
	Per tree.	Per barrel.	Per tree.	Per barrel.
Operations until picking time	$0.341	$0.192	$0.310	$0.078
Handling the crop	.617	.347	1.315	.329
Total	.958	.539	1.625	.407

CASH COSTS.

In the cost of the production of apples there are certain items for which a more or less direct outlay of cash, or its equivalent, is necessary. Such items as spray material, cover-crop seed, fertilizer, manure, barrels, storage, freight, etc., come under this head.

The manure cost is found by adding to the value of the manure the cost of applying it to the field. The total cost of the application in any one year is commonly charged to that year and the two years following on the basis of 50, 30, and 20 per cent, respectively.

In the Wellman orchard these cash costs proved to be 45 cents per barrel in 1911 and 46 cents per barrel in 1912. Of these, the barrel cost is the major portion, being 31 cents in 1911 and 42 cents in 1912, or 69.7 per cent and 91.7 per cent, respectively, of all cash costs. The complete record of cash costs is given in Table VI.

No expense was incurred in 1912 for cover-crop seed, but this was more than offset by the increase in the cost of barrels.

TABLE VI.—*Cash costs on the 14.74-acre Wellman apple orchard, containing 527 trees, for 1911 and 1912.*

Year and item of cost.	Distribution of cost. Spray.	Total.	Per acre.	Per tree.	Per barrel.
1911.					
Manure charge (50 per cent against 1911 apples)	....	$30.77	$2.087	$0.058	$0.033
Spray materials used:					
First spraying—					
Lime and sulphur, 40 gallons, at $0.04 [1]	$1.60	24.85	1.686	.047	.026
Lime and sulphur, 100 gallons, at $0.16 [2]	16.00				
Tobacco extract, 3 pints, at $1.562	4.69				
Lead arsenate, 32 pounds, at $0.08	2.56				
Second spraying—					
Lime and sulphur, 43 gallons, at $0.16	6.88	15.04	1.020	.029	.016
Lead arsenate, 102 pounds, at $0.08	8.16				
Third spraying—					
Lime and sulphur, 32 gallons, at $0.16	5.12	11.28	.765	.021	.012
Lead arsenate, 77 pounds, at $0.08	6.16				
Fourth spraying—					
Lime and sulphur, 15 gallons, at $0.16	2.40	5.28	.358	.010	.006
Lead arsenate, 36 pounds, at $0.08	2.88				
Barrels, 937, at $0.311	....	291.41	19.770	.553	.311
Seed for cover crop [3]	....	39.47	2.678	.075	.042
Total for season	....	418.10	28.364	.793	.446
1912.					
Manure charge (30 per cent against 1912 apples)	....	18.46	1.252	.035	.009
Spray materials used:					
First spraying—					
Lime and sulphur, 80 gallons, at $0.04 [1]	3.20	13.70	.929	.026	.006
Lime and sulphur, 75 gallons, at $0.14 [2]	10.50				
Second spraying—					
Lime and sulphur, 44 gallons, at $0.14	6.16	14.56	.988	.028	.007
Lead arsenate, 105 pounds, at $0.08	8.40				
Third spraying—					
Lime and sulphur, 52.5 gallons, at $0.14	7.35	17.43	1.182	.033	.008
Lead arsenate, 126 pounds, at $0.08	10.08				
Fourth spraying—					
Lime and sulphur, 35 gallons, at $0.14	4.90	16.64	1.129	.031	.008
Lead arsenate, 146.75 pounds, at $0.08	11.74				
Barrels, 2,104, at $0.421	....	885.78	60.094	1.681	.421
Total for season	....	966.57	65.574	1.834	.459

[1] Undiluted homemade solution: 36 pounds of lime, 80 pounds of sulphur, and 50 gallons of water. The cost of labor is included. Rate of dilution, 1 gallon of lime and sulphur solution to 7 gallons of water.
[2] Undiluted commercial lime and sulphur: Rate of dilution, 1 gallon of lime and sulphur solution to 10 gallons of water.
[3] Items of seed cost: Clover, 180 pounds, at 16 cents; oats, 22 bushels, at 40 cents; turnips, 7.5 pounds, at 25 cents.

FIXED COSTS.

The term "fixed costs" embraces all costs other than labor and cash costs that enter into and make up the total cost of production. Although these costs are indirect, they must be given due consideration before the total cost can be determined. Under this group are such items as interest and taxes on real estate, the cost of the use of machinery and use of buildings, and overhead expense. These fixed costs for the Wellman orchard for 1911 and 1912 are given in Table VII.

TABLE VII.—*Fixed costs on the 14.74-acre Wellman apple orchard, containing 527 trees, for 1911 and 1912.*

Item of cost.	Distribution of cost, 1911.				Distribution of cost, 1912.			
	Total.	Per acre.	Per tree.	Per barrel.	Total.	Per acre.	Per tree.	Per barrel.
Use of machinery [1]	$31.68	$2.149	$0.060	$0.034	$31.68	$2.149	$0.060	$0.015
Land rental (interest and taxes 5.905 per cent)	241.04	16.353	.457	.257	241.04	16.353	.457	.115
Overhead expense	22.19	1.505	.042	.024	29.74	2.018	.057	.014
Total fixed costs for season	294.91	20.007	.559	.315	302.46	20.520	.574	.144

[1] The machinery included here is used on several orchards on this farm, and the charge here shown is the pro rata share for this orchard, being about one-third of the total amount.

In the Wellman orchard these costs amounted to 31.5 cents per barrel in 1911 and 14.4 cents per barrel in 1912. As the total of these costs varies but little from year to year for the same orchard, the cost per barrel is directly proportionate to the yield.

The major portion of the fixed costs is in the interest on the investment and the taxes on the land. The land rental is figured at 5 per cent on the estimated inventory value of the orchard, plus the taxes, which amounted to 0.905 per cent on this same value. In 1911 this land rental was 81.8 per cent of the fixed costs and in 1912, 80 per cent.

No account has been taken of the depreciation of the orchard. This factor will depend largely on the variety of apples grown, the age of the trees, the soil and climate, and the cultural methods adopted. The presence of insect pests and fungous diseases and the thoroughness of their control will have their influence on the life of the orchard. Owing to insufficient data, no attempt is made to measure this item of cost. Nevertheless, it should be borne in mind by apple growers.

SUMMARY.

In Table VIII all the costs of operation are summarized for both the years specified. On this particular farm these show a total of $1.30 per barrel of marketable apples for 1911 and $1.01 for 1912.

The three most important items constituting this cost are labor, amounting to 40 per cent; the package (barrel), from 25 to 41 per cent; and the land rental, from 12 to 20 per cent. There are many other items, but these three constitute from 85 to 90 per cent of the total cost per barrel of marketable apples. Many growers do not realize that the money paid out for barrels alone is often more than the entire labor cost of production.

TABLE VIII.—*Summary of labor, cash, and fixed costs on the 14.74-acre Wellman apple orchard, containing 527 trees, for 1911 and 1912.*

Item of cost.	Distribution of costs, 1911.				Distribution of costs, 1912.			
	Total.	Per acre.	Per tree.	Per barrel.	Total.	Per acre.	Per tree.	Per barrel.
Labor	$504.91	$34.254	$0.958	$0.539	$856.66	$58.118	$1.625	$0.407
Cash	418.10	28.364	.793	.446	966.57	65.574	1.834	.459
Fixed cost	294.91	20.007	.559	.315	302.46	20.520	.574	.144
Total	1,217.92	82.625	2.310	1.300	2,125.69	144.212	4.033	1.010

In this connection it must be remembered that these figures refer only to the Wellman farm and are merely for the two years considered. They may or may not apply to any other farm in this same community. All fruit growers realize the wide variation in the important factors related to the cost of growing apples and the need for a careful consideration of these in any study of this problem. These factors will vary in respect to variety, age, and size of trees, soil, climate, method of management, and particularly in respect to the ability of the farmer as a manager. In further consideration of these figures it should be kept in mind that the data here presented pertain to an orchard that is over 50 years old and is well located for the production of good fruit.

Referring again to Table VIII, it will be noted that the cost per acre and per tree was much greater in 1912, yet the larger yield of apples made the cost per barrel 28 cents less than that of the preceding year. As regards fixed costs, they are fairly constant, being approximately $20 a year per acre on this particular orchard. The cash costs—that is, such expenses as spray materials and barrels—are largely dependent upon the amount and price of spray material, together with the number of barrels or other packages used. Hence, these items of expense will vary with the yield of marketable fruit.

The labor cost is influenced by the method of management. It is in this connection that the efficient organization of the entire farm, of which the orchard forms only one part, becomes an important factor in lessening the rate of both man and horse labor. On a farm where the apple orchard constitutes the only enterprise, there being no other source of farm income, it is evident that all the labor expended must be charged against the apple orchard. Hence, it is quite possible that the rate per hour of man and horse labor would be much higher than on a well-diversified farm, where the labor is better distributed throughout the year. The lowering of this rate on a diversified farm comes about through the other farm enterprises utilizing the labor during the periods when it is not needed in orchard work.

Persons taking up fruit growing as a specialty without any other sources of farm income are not following the experience of the best growers in the oldest apple-producing regions of this country. The Wellman farm is an excellent illustration of growing fruit in connection with other farm crops. The crops, such as beans, wheat, and hay, form no small part in lessening the operating costs of this orchard, in that fruit growing constitutes only one item of the farm business. In this way the overhead costs chargeable to the orchard are materially decreased, while in the case of the specialized apple farm all such costs must be borne entirely by the orchard. The reader is urged to bear in mind that the data which have been presented refer only to a particular orchard on a single farm and give only the expense factors incident to the maintenance and operation of this well-cared-for mature orchard. This publication is intended to illustrate a method which, if followed by apple growers, will enable them to analyze the important factors entering into the cost of operating and maintaining their orchard industries and to determine the relation which the various cost factors bear to one another in years of varying crop production. By adopting this method the independent grower will be able to determine the actual cost of maintaining and operating his fruit enterprise on his own farm.

No intelligent grower will assume that these figures are actual costs on his own farm, but he should determine for himself the cost of producing his fruit.

Apple growing as a commercial business has in many regions reached a high state of development. With the increased development keener competition will result. In order to realize profits, the producer must manage his business efficiently. The men most favorably situated and who are experienced and efficient will be able to produce apples cheapest. The lessening of the cost will not necessarily be due to differences in cultural methods, the reduction of package costs, or the decrease in the wages of the help, but to better management of the farm as a unit.

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Contribution from the Bureau of Entomology, L. O. Howard, Chief.
September 10, 1914.

REPELLENTS FOR PROTECTING ANIMALS FROM THE ATTACKS OF FLIES.[1]

By H. W. Graybill, D. V. M.,[2]
Assistant Zoologist, Zoological Division, Bureau of Animal Industry.

INTRODUCTION.

During the warm season of the year cattle, horses, and mules suffer a great deal of annoyance and more or less injury as the result of the attacks of various biting flies, and numerous requests are received in this department concerning methods of relieving the animals from these attacks. The flies that cause the greatest annoyance to domestic animals are the stable fly (*Stomoxys calcitrans* L.) and the horn-fly (*Lyperosia irritans* L.). The horseflies (Tabanidæ) are of some importance and individually their attacks are sanguinary, but they are not the cause of as much injury as either of the two species of muscids that have been mentioned. The bot flies (Œstridæ) affecting horses, cattle, and sheep are not biting flies and only visit these animals to deposit their eggs. The larvæ of these flies, however, are parasitic and are the cause of considerable annoyance and more or less loss, and for this reason repellents are sometimes applied to animals to prevent the adults from depositing their eggs. In the case of the horse and the ox, parasiticides are applied to the skin to destroy the eggs of bot flies that have already been deposited.

The screw worm (*Paralucilia macellaria* Fab.) likewise is not parasitic in its adult state, and visits animals only to deposit its eggs in wounds where the larvæ, when they emerge, may find nourishment and complete their growth. There are also various other species of flies that may deposit their eggs in wounds and whose larvæ become parasitic.

In the United Kingdom and Holland a bluebottle fly (*Lucilia sericata* Meig.) deposits its eggs on the soiled wool about the anus,

[1] The investigations reported in this paper were undertaken by the Bureau of Animal Industry incidentally during the progress of other investigations concerning stock dips. Although comparatively few repellents were tested, it is believed that the data obtained concerning substances which may be applied to live stock to protect them from flies are of interest and value to the live-stock industry.

[2] Resigned, April 16, 1914.

chiefly in young sheep, sometimes in adult sheep when badly kept, and the larvæ hatching from the eggs become parasitic in the skin. In Australia several species of blowflies (*Calliphora oceanicæ* Desv., *C. villosa* Desv., and *C. rufifacies* Desv.) produce a similar condition in sheep. Recently a cutaneous invasion of sheep with dipterous larvæ occurring at Cobham, Va., was reported to this department, but the fly responsible for the trouble has not been identified. The application of repellents and parasiticides is indicated in case sheep are subject to the attacks of such flies.

The house fly (*Musca domestica* L.) commonly visits wounds on animals to suck up the exudates that occur there. It is the cause of considerable annoyance to animals in this way; it prevents wounds from healing and may introduce into a wound agents of infection adhering to its body. Repellents are therefore indicated and are frequently used on wounds to keep house flies away and also to keep away such flies as may deposit their eggs in wounds, such, for example, as the screw-worm fly.

The use of fly repellents is resorted to largely for the purpose of relieving animals of the torment of biting flies or of preventing infestation with the larvæ of flies, without any reference to the control or eradication of such pests. In the case of such flies as the stable fly and the hornfly, the use of repellents can be of only secondary importance as an eradicative measure, since a much more effective means of getting rid of these pests lies in preventing them from breeding. This may be done by preventing access of the flies to materials such as manure, etc., in which they deposit their eggs, and by destroying the young stages that may be present in such materials. However, the eradication of these flies in most instances, or even a reduction in their numbers in many cases, is out of the question, so that it is necessary to resort to the use of repellents or other means to give relief to animals.

In the case of the horseflies, preventing them from biting is probably as important a factor as can be taken advantage of in bringing about control, yet it must be admitted that this means can be of only very little importance. In the case of the bot flies and the screw-worm flies, the use of repellents against the adults and of parasiticides against the eggs and larvæ is an important method of eradication as well as a valuable means of protecting animals.

INJURY CAUSED DOMESTIC ANIMALS BY BITING FLIES.

Aside from the transmission of various animal diseases by biting flies, a matter of much less importance in this country than in the Tropics, flies are generally assumed to be responsible for enormous losses to farmers and stockmen. Because of the great numbers in which flies occur, the irritation they cause animals, the blood they abstract, the movements they cause animals to make in fighting them, and the unfavorable influence they have on the temper of dairy cows, it is believed by both scientist and layman that flies are responsible for very great financial losses.

According to Delamare (1908), a German professor named Lehmann is stated to have established that the supplementary expenditure of energy corresponding to the agitation caused horses by the attacks of flies amounts to a pound of oats a head per day. Moore (1903), of the South Dakota Agricultural Experiment Station, says: "When we consider the intimate relationship existing between the milk yield and the physical comfort of the cow, no question can be raised as to the benefit obtained by mitigating so far as possible the annoyances of these pests." Hopkins (1891) states that the hornfly so annoys cattle by its bite that the cows fail in milk and other cattle fail in flesh. Garman (1892) says: "The injury done to cattle has been greatly overestimated in some instances; yet there can be no doubt that the yield of milk from cows greatly worried by hornflies is much reduced, and growing and fattening stock are doubtless retarded by their attacks." Marlatt (1910) states: "During the first years of the hornfly, when it was a new and little understood menace to cattle, the losses occasioned by it were undoubtedly much exaggerated. Nevertheless, the loss when the fly is abundant is still very considerable, showing in reduced vitality, lack of growth, or lessened yield of milk, the production of milk often being cut down from one-fourth to one-half. In Canada the late Dr. James Fletcher estimated the loss in Ontario and Quebec at one-half the product of meat and milk." Bishopp (1913) describes an unusual outbreak of the stable fly in 1912 in northern Texas and refers to various other outbreaks that have occurred in the United States. In referring to the injury due to the fly he states that many horses and cattle became so weak that they gave up the fight against the pest. In a few cases in which the animals were not protected they succumbed in a short time. Texas fever was rekindled in an acute form in cattle that became weakened as a result of the flies, and in many cases death resulted. The influence of the flies on the milk production was marked, the reduction being from 40 to 60 per cent, and in some cases cows were completely dried up. Horses and mules lost 10 to 15 per cent in weight during the outbreak. Cattle likewise suffered a great reduction in weight. It is estimated that in northern Texas over 300 head of cattle, mules, and horses were killed directly or indirectly as the result of the fly attack. This loss is estimated at $15,000, and the loss in the milk production is placed at $10,000, and other losses are stated to surpass these.

Fuller (1913) has described an outbreak of the stable fly along the east coast of South Africa. All classes of animals are said to have suffered greatly from worry and anemia. Many cattle were killed, and horses and cattle stampeded into the sea and into rivers to obtain relief. The outbreak followed heavy rains.

The experimental evidence with regard to the losses due to flies that is available in this country does not seem to indicate that they are as a rule of such serious consequence as the foregoing statements would lead one to believe. The seriousness of such outbreaks as Bishopp and Fuller refer to can not be questioned. Carlyle (1899), at the Wisconsin Agricultural Experiment Station, conducted an experiment relative to injury due to flies in which two lots of seven cows each were used. Lot No. 1 was kept during the day in a paddock provided with shade trees, while lot No. 2 was protected from flies by being kept in a screened stable. The cattle in both lots were kept on the pasture during the night and taken off at 9 o'clock in the morning. The experiment was continued for a period of four weeks. The cattle in the lot protected from flies ate 835 pounds more green corn than those that were unprotected. All the cows lost in weight, but the protected cows lost nearly three times as much as the others. In comparing the milk and butter production of the first two weeks of the experiment with that of the two weeks just preceding the experiment it was noted that there was a decrease in both milk and butter. The milk reduction was greater for the protected animals and the butter reduction was greater for the unprotected animals. The conclusion reached was that the greater amount of butter yielded by the protected lot was not sufficient to pay for the increased trouble and expense entailed in stabling the cows during the greater part of each day.

Kent (1903), in an experiment at the Oregon Agricultural College and Experiment Station, used a proprietary repellent on four dairy cows. Four untreated cows served as controls. The treated cows gained a total weight of 265 pounds while the untreated ones gained 212 pounds. In comparing the milk and butter records of two cows from each lot that were in about the same stage of lactation with the records of the same cows during the two months just preceding the experiment it was found that the treated cows lost about 10 per cent less than the cows not treated.

Beach and Clark (1904), at Storrs Agricultural Experiment Station, Conn., tested a proprietary fly repellent which the manufacturers claimed would effect a tremendous saving during the fly season. The experiments covered a period of two seasons and the cows were sprayed thoroughly once a day. The conclusions reached by the authors are as follows: "1. The annoyance of cows by flies seems to be overestimated. 2. Certain proprietary ointments known as 'fly removers' will protect the animal to a greater or less extent, but their use has little or no effect on the milk or butterfat secretion."

Eckles (1905) carried on experiments for two seasons at the Missouri Agricultural Experiment Station with a proprietary repellent for the purpose of determining whether the use of a repellent on dairy cows would have any influence on the amount of milk and butter produced. During the first season 16 cows were used and during the second season 22 cows were used. The fly season was divided into periods of two weeks, and the herd was sprayed each morning during alternate periods. A comparison was made between the sprayed and unsprayed periods. The conclusion reached by the author was that the use of the fly repellent was fairly effective in preventing the annoyance from flies if applied every morning, but that the yield of milk and fat was not appreciably affected by its use. The only advantage observed was that the cows stood more quietly during milking. With regard to the shrinkage in milk production during hot weather, the author has the following to say: "The rapid shrinkage that occurs in the yield of a cow during the hottest summer months is a well-established fact, but is probably not so much on account of flies as to failure to graze sufficiently, if on pasture, on account of the heat."

THE INFLUENCE OF COLOR ON FLIES.

Several years ago Dr. Schroeder, of the Bureau of Animal Industry, called my attention to some pictures of Holstein cattle he had taken in connection with some tuberculosis work, in which the flies on the animals were confined almost exclusively to the black-colored spots. Beach and Clark (1904) state that some animals suffer more from hornflies than others and that dark-colored animals suffer more than light-colored ones. Marlatt (1910) states that the hornfly exhibits a certain preference for red or other dark-colored cattle, and that such animals are more thickly infested has been frequently noted. He states, however, that when the flies are abundant this preference is not so strongly marked.

Marre (1908) refers to a discovery which a farmer in the vicinity of St. Cyr made relative to the influence of color on flies. The farmer had 170 cows in a number of stables and noted that flies had a marked aversion for blue. The idea came to him to add blue to the whitewash with which he coated the walls of his buildings each year. After doing this the flies left his cattle stables.

The formula used for the wash is as follows:

Water	100 liters (105.6 quarts, or 26.4 gallons).
Lime (slaked)	5 kilos (11 pounds).
Ultramarine blue	500 grams (1.1 pounds).

Two applications, one in June and one in August, are recommended. The present writer is not aware whether this observation has been corroborated or not.

INTERNAL REMEDIES FOR REPELLING FLIES.

It would hardly seem likely that a drug could be administered to animals that would prevent flies from making their customary attacks. However, Ochmann (1911) has recommended potassium tellurate for this purpose. According to him this chemical does not affect the general health of animals. The hair, however, becomes temporarily rougher, paler, and drier. The expired air, the perspiration, and the feces take on an intensely offensive garlic odor which persists for a long time.

Two dogs received on two successive days each 0.25 gram of potassium tellurate. The results appeared on the day of the first administration and lasted three to four weeks. The olfactory sense of one dog suffered considerably. One of the dogs formerly troubled with ticks was no longer affected. The dogs were protected from flies.

An ass was given 0.25 gram of the chemical in the feed for three days. The action was negative. Another ass received on three successive days 0.25 gram. On the second day the odor appeared in the breath and disappeared one day after the last dose.

A mule received on three successive days 1.5 grams. The odor appeared on the day following the first administration and gradually disappeared in 10 days. There were no unfavorable results. Another mule was given on three successive days 0.5 gram. The odor appeared on the day following the second dose and disappeared one day after the last dose. A mule received on two successive days 2 grams. An intense odor appeared on the second day and disappeared after six days.

The author states that flies lighting on the animals were repelled.

Mayer (1911) conducted experiments for the purpose of verifying Ochmann's results, and reached quite different conclusions. Ten experiments were carried out, nine on horses and one on a cow. Each animal received in all 10 grams in single doses of from 1 to 5 grams. The best method of administering the drug was to dissolve the salt in drinking water. Subcutaneous administration leads to dry necrosis. The drug was taken unhesitatingly and caused no ill results except occasionally a staring coat in fine-haired animals. The garlic odor of methyltellurid appeared in the breath of the cow and was present for a long time. The odor appeared to a very slight degree in the breath of three of the horses, but disappeared very soon.

The author states that the administration of potassium tellurate in all cases failed to protect animals from flies.

It would therefore seem likely that this internal remedy is not efficacious. If it or any other internal remedy were found efficacious, it is doubtful whether it could be administered to dairy cows without imparting an odor to the milk. On the whole, therefore, the use of internal remedies seems to be an extremely unpromising means of repelling flies.

EXTERNAL REMEDIES FOR REPELLING FLIES.

There are almost innumerable homemade and proprietary external remedies for repelling flies. They contain various substances that are distasteful to the insects. Many of them contain strongly odoriferous ingredients that have a repelling influence on flies. The qualities to be sought in a satisfactory repellent are: Absence of toxic and other detrimental properties when applied externally to animals; a marked repellent action on flies; and a duration of this action for a reasonable length of time. A common defect of many otherwise rather good repellents is the very short period during which they are effective. Some repellents are undoubtedly toxic and must be used with care.

METHODS OF APPLYING REPELLENTS.

Repellents as a rule are in the form of liquids and may be applied by means of a dipping vat, a pail spray pump, an atomizer such as that commonly used in gardens and greenhouses for applying insecticides to plants, or by means of a rag or a paint brush. The method employed necessarily depends to a very large extent on the number of animals to be treated, the physical character and toxicity of the preparation, its cost, and the individual preference of the farmer or stockman. Some preparations, either because of their cost or their toxicity, or for some other reason, are not adapted for use in a dipping vat or for application by means of a spray pump. Others may be applied by any one of the methods mentioned.

Marlatt (1910) describes a special splash board for vats, devised by J. D. Mitchell. By means of this board the splash caused when the animal plunges into the vat is thrown back into the vat in the form of a spray and many of the flies are wetted and carried down with the dip. It is said that with vats equipped with such splash boards from 75 to 80 per cent of the hornflies are killed.

EFFICACY OF PROPRIETARY REPELLENTS.

Lindsey (1903), at the Massachusetts Agricultural Experiment Station, tried out 10 proprietary fly repellents. He found that four were quite satisfactory, four others were less satisfactory, and two were unsatisfactory. The chief defect of the second group seemed to be that they were not lasting. It is stated that these fly repellents are sold at retail from $1 to $1.50 a gallon.

POWDERS AS REMEDIES.

Smith (1889), of the New Jersey Agricultural Experiment Station, found by experiment that two powders were adapted for destroying hornflies and stable flies, namely, pyrethrum powder and tobacco powder. Pyrethrum acted promptly, but was objectionable from a practical standpoint because of its expense and because it lost its strength soon after application. Tobacco was found very much more satisfactory though the killing power was less. He recommended a proprietary powder having for its base tobacco dust and containing crude carbolic acid or creosote. The method of protecting cattle from the hornfly that he suggested was to apply carbolated fish oil to the belly, udder, and those parts of the animal where powder could not well be used, and to apply tobacco powder to the base of the horns, the back, and at the root of the tail. The effect of the oil is to repel and that of the tobacco to kill flies that attempt to feed.

OILS AS REPELLENTS.

Almost any kind of oil, whether it has a pungent or disagreeable odor or not, will repel flies to a certain extent. The mere physical condition of the hair and skin of an animal treated with oil seems to be repugnant to flies. Oils are used pure or in the form of an emulsion, or in combinations or mixtures. Crude petroleum, cottonseed oil, fish or train oil, and light coal-tar oil may be used pure.

Crude petroleum may be used in the form of an emulsion. The formula and method of preparing it so as to make 5 gallons of 80 per cent emulsion are as follows:

Hard soap	1 pound.
Soft water	1 gallon.
Beaumont crude petroleum	4 gallons.

In preparing the emulsion the soap should be shaved up and placed in a kettle or caldron containing the required amount of water. The water should be brought to a boil and stirred until the soap is entirely dissolved. Enough water should be added to make up for the loss by evaporation during the process. The soap solution and the required amount of oil are then placed in a convenient receptacle and mixed either by stirring or by means of a spray pump. If properly prepared the stock emulsion will keep indefinitely. When required for use the stock emulsion should be diluted, one part of the emulsion to three parts of water being used. The diluted emulsion does not remain uniformly mixed, so if allowed to stand it should be thoroughly mixed by stirring before using.

Jensen (1909) recommended the following mixture containing crude petroleum for dairy cows. He states that it remains on cattle for at least a week.

Common laundry soap	1 pound.
Water	4 gallons.
Crude petroleum	1 gallon.
Powdered naphthalin	4 ounces.

Cut the soap into thin shavings and dissolve in water by the aid of heat; dissolve the naphthalin in the crude oil, mix the two solutions, put them into an old dasher churn, and mix thoroughly for 15 minutes. The mixture should be applied once or twice a week with a brush. It must be stirred well before being used.

A mixture of cottonseed oil and pine tar in the proportion of two parts of the former to one part of the latter has been recommended to relieve cattle of flies.

Fish or train oil is generally rated as one of the best repellents. Its protective action is said to last from two to six days, depending on the temperature and humidity. A great many mixtures have been recommended in which fish oil occurs as an important ingredient. Moore (1903) recommended the following mixture for use on dairy cows:

Fish oil	100 parts.
Oil of tar	50 parts.
Crude carbolic acid	1 part.

The cost of the mixture was about 35 cents per gallon. The mixture was applied with a small hand spray pump. One application was effective for two days.

Bishopp (1913) gives the following formula for a mixture that is said to be very effective in keeping flies from live stock, when applied lightly:

Fish oil	1 gallon.
Oil of tar	2 ounces.
Oil of pennyroyal	2 ounces.
Kerosene	½ pint.

Parrott (1900), at the Kansas Agricultural College, found that repellents were not as effective in Kansas as they were said to be in other States. Fish oil was effective for less than two days.

The following formula is recommended by him as being as effective as fish oil, and at the same time cheaper and more lasting:

Pulverized resin	2 parts (by measure).
Soap shavings	1 part.
Water	½ part.
Fish oil	1 part.
Oil of tar	1 part.
Kerosene	1 part.
Water	3 parts.

Place the resin, soap shavings, the one-half part of water, and fish oil together in a receptacle and boil until the resin is dissolved. Then add the 3 parts of water, following with the oil of tar mixed with the kerosene. Stir the mixture well and allow it to boil for 15 minutes. When cool the mixture is ready for use and should be stirred frequently while being applied. Application should be made with a brush. One-eighth to half a pint is required for each animal. The cost of the mixture is given as 30 cents a gallon.

The present writer has not made or used the above repellent. Its formula and method of preparation seem too complex for wide use. It would appear that great caution should be exercised in boiling the mixture because of the inflammability of some of the ingredients.

The same author recommends the following formula for horses. It is said to be effective for three to four hours and even longer:

Fish oil	2	quarts.
Carbolic acid (crude)	1	pint.
Pennyroyal	1	ounce.
Oil of tar	8	ounces.
Kerosene	[1] 1½	quarts.

The cost is given at about 80 cents a gallon. The mixture must be applied with an atomizer and not with a brush.

Carlyle (1899), of the Wisconsin Experiment Station, states that fish oil to which is added a little oil of tar and a little sulphur will serve to protect cows from hornflies for four to five days if the weather is fine. He states that none of the remedies seem to be effective against the stable fly an hour after being applied.

Otis (1904) recommends a repellent worked out by the entomological department of the Kansas station. The formula is as follows:

Resin	1½	pounds.
Laundry soap	2	cakes.
Fish oil	½	pint.
Water enough to make	3	gallons.

Dissolve the resin in a solution of soap and water by heating. Add the fish oil and the rest of the water. Apply with a brush. If to be used as a spray, add one-half pint of kerosene. The cost is 7 to 8 cents a gallon.

Fish oil containing a small admixture of carbolic acid has been used with good success as a repellent.

Lindsey (1903), at the Massachusetts Agricultural Experiment Station, found light coal-tar oil quite satisfactory. This oil is described as the lighter of two oils derived from tar. It is a dark, thin oil with a strong creosote odor. It was applied as a spray.

[1] Or enough to make 1 gallon of mixture.

Kerosene mixed with cottonseed oil or in the form of an emulsion may be used for repelling flies. Spencer (1904), at the Virginia station, used an emulsion of kerosene in a special spraying apparatus for destroying the hornfly. The formula and method followed in preparing the emulsion are given below:

Yellow soap	½ pound.
Soft water	1 gallon.
Kerosene oil	2 gallons.

Shave the soap fine and dissolve in water at boiling temperature. Place the kerosene in a barrel, add the hot-soap solution, and by means of a spray pump agitate for 15 to 20 minutes, or until emulsification is complete. One gallon of water is added to prevent the solution becoming thick. This is a stock solution and should be diluted in the proportion of 1 to 5 of water. The diluted emulsion tends to separate, so only the amount needed should be diluted each time.

It is stated that at the Virginia Agricultural Experiment Station daily sprayings for a period of two weeks reduced the hornflies to a point of insignificance. The flies were killed in passing through the spray.

A milk emulsion of kerosene may be made as follows: To 1 part of milk add 2 parts of kerosene and mix by means of a force pump, or in some other way. The creamy emulsion that results is to be diluted with 8 or 10 times the bulk of water.

Mayer (1911) found that laurel oil applied to the skin of cattle and horses repelled the flies. The oil produced an inflammation of the skin in some of the tests. The oil applied to bedsores of horses repelled the flies and produced no change in the sores.

Laurel oil and linseed oil in the proportions of 1 to 10 repelled flies from a bedsore on the foreleg of a horse for five days. The entire right side of a horse was rubbed with the oil. No flies were seen on the right side and great numbers were present on the left side. The action lasted for 12 days. A light application of oil to a horse was effective for only two days. This mixture produced no inflammation of the skin.

The following mixture was also tested by Mayer: Laurel oil, 1 part; dilute alcohol, 4 parts; and olive oil, 5 parts. In place of dilute alcohol denatured alcohol with water may be used, and in place of olive oil linseed oil may be used. The mixture was tried on horses, but the results were not so good, as the mixture did not stick. The action lasted five days.

Rancid oil should not be used on account of its irritating action.

REPELLENTS FOR APPLICATION TO WOUNDS.

Jensen (1909) gives three formulas of repellents for application to wounds:

Formula No. 1:

Oil of tar	8 ounces.
Cottonseed oil to make	32 ounces.

Formula No. 2:

Powdered naphthalin	2 ounces.
Hydrous wool fat	14 ounces.

Mix into an ointment.

Formula No. 3:

Coal tar	12 ounces.
Carbon disulphid	4 ounces.

Mix; keep in a well-stoppered bottle and apply with a brush.

Mixtures Nos. 2 and 3 are said to adhere to moist surfaces, and No. 3 is said, in addition, to form a coating over raw surfaces and protect from the screw-worm fly.

The editor at the close of the article in which the above formulas are given adds the following formula:

Oil of turpentine	1 dram.
Phenol	1 dram.
Cottonseed oil to make	4 ounces.

Mix and apply freely to wounds.

It is stated that this remedy is highly effective and is used widely in the South. It is said to induce healthy granulation of wounds.

EXPERIMENTAL TESTS OF VARIOUS SUBSTANCES AND MIXTURES FOR REPELLING FLIES.

For the purpose of determining the efficacy of various substances and mixtures for repelling flies, a number of tests were made by the present author at the Bureau of Animal Industry Experiment Station during the summers of 1912 and 1913. The results of these tests are given below. In making various mixtures for the purpose of trial the plan adopted was to combine a pungent or odoriferous substance with an oil which served mainly as a vehicle.

CRUDE CARBOLIC ACID.[1]

The following tests were made with 10 per cent crude carbolic acid in cottonseed oil:

On July 22, 1912, a calf was sprayed with a mixture of 10 per cent crude carbolic acid in cottonseed oil. About 2 quarts of the mixture were applied. The calf was discovered down about 7 to 10

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[1] A sample of the crude carbolic acid used in these tests was examined in the Biochemic Division of the Bureau of Animal Industry, and was found to contain 21.8 per cent phenols.

minutes later with symptoms of carbolic-acid poisoning. There was salivation, dyspnea, trembling, paralysis, inability to rise, rapid breathing, and rapid and irregular beating of the heart.

Another calf was sprayed on the same date with about $1\frac{1}{2}$ quarts of the mixture. The calf showed distinct symptoms of carbolic-acid poisoning in 6 minutes. It showed a tendency to fall in 8 minutes, and fell in 14 minutes. The symptoms in the order in which they occurred were: Salivation, dyspnea, muscular tremors, loss of muscular control, and finally motor paralysis. The breathing was rapid and shallow.

It was necessary to destroy both of the animals.

July 15, 1913, applied the mixture to a calf by means of a brush. Used $2\frac{2}{3}$ ounces of the mixture. The repellent action was very marked. July 16, about 18 hours later, the animal was worried as much by flies as were the controls. Oil was present only along the back. There was only a very faint odor of carbolic acid. The protection was practically nothing. There were no symptoms of poisoning.

The results obtained with crude carbolic acid may be summarized as follows: In the case of the first two calves treated it shows that carbolic acid in cottonseed oil is absorbed through the skin. It is well known that carbolic acid, when combined with oil, loses its caustic properties, but its toxic properties still remain, as evidenced by the above cases of poisoning. It seems certain that in the case of any such mixture, no matter how small the content of carbolic acid, a certain amount of the same must be absorbed. The amount absorbed will depend, other things being equal, on the amount of the mixture applied. In the third test that was made, the same strength (10 per cent) mixture was used, but it was applied with a brush and only to the amount of $2\frac{2}{3}$ ounces. There were no symptoms of poisoning. It is therefore evident that a 10 per cent mixture of crude carbolic acid (21.8 per cent phenols) in cottonseed oil may be used with safety if the application is very light. It is undoubtedly true that a very much weaker mixture of carbolic acid if applied liberally would produce toxic symptoms.

The repellent action of this mixture, however, does not endure. Its action was very marked at first, but lasted less than 18 hours. It would be necessary therefore to apply this mixture every day. In order to ascertain whether daily applications of the mixture could be made without danger to the animal, a calf was treated with this mixture on October 2, 3, 4, 6, 7, 8, 9, 10, 11, and 13. The mixture was applied with a brush. There were no symptoms of poisoning or other untoward results.

PINE TAR.

TEN PER CENT PINE TAR IN COTTONSEED OIL.

July 29, 1912, sprayed a cow with 10 per cent of pine tar in cottonseed oil. Used 3½ quarts of the mixture.

July 30, the cow was looking droopy. The ears were hanging.

July 31, the hair was still oily. There was no odor of tar. The animal was bright and perfectly normal. No hornflies were observed. A few stable flies were present on the legs and body. The animal was not fighting the flies, whereas unsprayed animals were constantly switching their tails.

August 1, some oil was still present. Some stable flies were present, especially on the legs. Animal does not fight flies as much as do the untreated animals.

August 3, oil still present on the back, croup, and thighs. It is very sticky. There is little or no protective action.

TWENTY PER CENT PINE TAR IN COTTONSEED OIL.

July 15, 1913, treated a cow with 20 per cent pine tar in cottonseed oil. Used 5⅓ ounces of mixture. It was applied with a brush. The protection was marked but not quite so effective as either 10 per cent crude carbolic acid or 10 per cent oil of tar in cottonseed oil. July 16, about 18 hours later, the cow fought flies as much as did the controls. There was some oil present on the neck, back, and on the fore legs. There was no odor of tar. There was little or no protective action evident at this time.

A HALF-AND-HALF MIXTURE OF PINE TAR AND COTTONSEED OIL.

July 31, 1912, sprayed a calf with a half-and-half mixture of pine tar and cottonseed oil. Used about 2 quarts of fluid. The mixture was too thick to spray well in pump. The animal was sprayed very unevenly and some spots were not covered. Two types of nozzles were used, but a satisfactory spray was not developed.

August 1, there was plenty of oil present and also an odor of tar. Tar was visible here and there on the hair. No flies were observed.

August 3, some oil was still present. There was a slight odor of tar. A repellent action was still noticeable on the back, croup, and thighs.

July 31, a second calf was sprayed. Used about 2 quarts, which was not enough to cover the animal properly.

August 1, there was plenty of oil present, and there was a strong odor of tar. No flies were observed.

August 3, the oil and tar odor still present. A distinct repellent action on stable flies was still noticeable.

FIFTY PER CENT PINE TAR IN BEAUMONT OIL.

August 19, a cow was treated with 50 per cent pine tar in Beaumont oil. The mixture was applied with a brush.

August 20, the mixture had been rubbed off the sides and abdomen. The odor of tar was still present. The hair was rather untidy. Flies were present only on underside of abdomen.

August 21, the cow was stiff. The mixture was still present on the back. There was no repellent action.

SUMMARY OF RESULTS WITH PINE TAR.

It is noted from the first test made that a liberal application of 10 per cent pine tar in cottonseed oil caused the animal to look droopy. It is probable that this was due to a toxic action of the tar. The odor of the tar had disappeared on the second day following the treatment. The repellent action lasted for three days. Some oil was present five days after the treatment.

In the test in which 20 per cent of pine tar was used, the mixture was applied with a brush and only 5½ ounces were used. The repellent action was marked, but not so great as in the case of 10 per cent crude carbolic acid or 10 per cent oil of tar. The repellent action lasted less than 18 hours. The odor of tar had disappeared at that time.

In the third test in which a half-and-half mixture of pine tar and cottonseed oil was used, the mixture was applied liberally by means of a spray pump. The repellent action lasted more than three days in the case of both animals treated. The mixture is too thick to be used in a spray pump.

In the last test, in which a half-and-half mixture of pine tar and Beaumont oil was used, the repellent action lasted less than two days. This mixture had a detrimental effect in that it caused the animal to become stiff.

There seems to be no danger to animals in applying tar in cottonseed oil for the purpose of repelling flies. In the first test there were slight symptoms of poisoning, but the amount of 10 per cent mixture applied (3½ quarts) was much more than would ever be applied to an animal to protect it from flies.

It is evident from the second test that when a pine-tar-cottonseed-oil mixture of moderate strength is applied in quantities such as it is economical to use, the applications will have to be made every day in order to provide protection.

OIL OF TAR.[1]

TEN PER CENT OIL OF TAR IN COTTONSEED OIL.

July 22, 1912, sprayed a calf with 10 per cent oil of tar in cottonseed oil. Used about 2 quarts of the mixture.

July 23, the oil was still evident. No hornflies were observed. Stable flies were seen to light on the hair but left immediately. Some stable flies were seen on the legs of the animals.

July 25, the odor of the oil of tar had entirely disappeared. The hair was still oily but flies were seen to light on the oily spots.

July 29, there was no oil present.

July 15, 1913, applied 3⅔ ounces of the mixture to a calf by means of a brush. The repellent action was very marked.

July 16, about 18 hours later, the calf did not fight the flies quite so much as did the controls. There was no odor of tar. There was a very slight evidence of oil on the sides and back but no repellent action could be observed.

HALF-AND-HALF MIXTURE OF OIL OF TAR AND COTTONSEED OIL.

August 22, 1912, sprayed a calf with a half-and-half mixture of oil of tar and cottonseed oil. Used about 2 quarts of the mixture. The animal almost immediately began to show signs of sickness. The eyes were half closed. The skin about the eyes, on the face, and at the corners of the mouth was wrinkled. There was slight salivation. These symptoms were followed by a slight swaying in the hind quarters when the animal walked. Finally the gait became staggering and the animal fell from time to time and arose again only with the greatest difficulty.

August 26, when the next observation was made, the animal had entirely recovered. There was no repellent action noticeable.

TEN PER CENT OIL OF TAR IN BEAUMONT OIL.

July 22, 1912, sprayed a calf with 10 per cent oil of tar in Beaumont oil. Used about 2 quarts of the mixture.

July 23, oil was present on the hair. There were a very few stable flies on the legs. No hornflies were observed.

July 25, more oil was present on the hair than in the case of a calf sprayed on the same date with a mixture in which cottonseed oil served as the base.

July 29, oil was present on the back and rump. No hornflies were observed.

[1] A sample of the oil of tar used in these experiments was examined in the Biochemic Division of the Bureau of Animal Industry and was found to contain phenols, volatile with steam, 14 per cent.

August 7, 1913, a calf was treated with 10 per cent oil of tar in Beaumont oil. The mixture was applied with a brush. The repellent action was marked.

August 8, no odor of tar was noticeable. The oil was rubbed off the abdomen, the sides, and outside of the thighs. Some stable flies were present on the legs. Only a very few hornflies were present.

FIFTY PER CENT OIL OF TAR IN BEAUMONT OIL.

August 19, 1913, a cow was treated with a mixture of 50 per cent oil of tar in Beaumont oil. The mixture was applied with a brush. There was a slight salivation, and the cow remained rather quiet following the treatment. It seems certain that there were symptoms of phenol poisoning.

August 20, the odor of the oil of tar was still present. Only a few stable flies were present on the legs. Other animals in the same pen were covered with flies. The mixture had disappeared from the sides and abdomen.

August 21, the cow was a little stiff. Oil was still present on the back. The cow was protected very little from the flies.

SUMMARY OF RESULTS WITH OIL OF TAR.

In the first test with 10 per cent oil of tar in cottonseed oil the mixture was applied with a spray pump. About 2 quarts of the liquid were applied. The repellent action lasted less than three days.

In the second test the mixture was applied by means of a brush, and 3⅔ ounces were used. The repellent action, which was very marked at first, had nearly disappeared at the end of 18 hours.

In the third test a half-and-half mixture of oil of tar and cottonseed oil was applied with a spray pump. About two quarts of the mixture were used. There were symptoms of poisoning. The next observation was made four days later, at which time there was no repellent action.

In the fourth test 10 per cent oil of tar in Beaumont oil was applied with a spray pump. About 2 quarts of the mixture were used. There were no symptoms of poisoning.

In the fifth test 10 per cent oil of tar in Beaumont oil was applied with a brush. On the following day the odor of tar had entirely disappeared and the repellent action had almost entirely ceased.

In the last test 50 per cent oil of tar in Beaumont oil was applied with a brush. The protection lasted about two days. There were mild symptoms of poisoning and the animal became slightly stiff.

The repellent action of 10 and 50 per cent of oil of tar in cottonseed oil or in Beaumont oil is very marked, but when applied in such quantities as it is economical to use the action lasts less than a day when cottonseed oil is used, and about two days when Beaumont oil is used. As shown by the third test, 50 per cent oil of tar is dangerous when applied in large quantities.

The last test shows that 50 per cent oil of tar in Beaumont oil when applied in small quantities with a brush is also dangerous. The increase of the content of oil of tar from 10 to 50 per cent does not seem to increase the duration of the repellent action materially, as indicated by tests 1 and 3, but the 50 per cent Beaumont oil mixture protected twice as long as the 10 per cent mixture.

For the purpose of determining whether daily applications of 10 per cent oil of tar in cottonseed oil would produce poisoning or other untoward results, a calf was treated with the mixture on October 2, 3, 4, 6, 7, 8, 9, 10, 11, 13, and 14. The mixture was applied with a paint brush. No symptoms of poisoning resulted, and the skin remained unaffected.

THE MOORE FORMULA.

October 4, 1912, a calf was sprayed with the following mixture:

Fish oil	100 parts.
Oil of tar	50 parts.
Crude carbolic acid	1 part.

About three quarts of the mixture were used. The animal appeared sick after being sprayed. It was restless and there was salivation.

October 7, the animal was very oily. There was present an odor of tar and fish oil. Flies were still repelled.

July 16, 1913, a bull calf was treated with the above mixture, which was applied with a brush, and 6 ounces were used. The repellent action was marked. There were no symptoms of poisoning.

It is noted from the first of the above tests that the application of the Moore mixture in large quantities is dangerous. Such a liberal application, however, would never be made in practice. The repellent action was still evident on the third day. In the second test a small quantity of the mixture was applied to a calf by means of a brush and no symptoms of poisoning resulted.

TEN PER CENT OIL OF CITRONELLA IN COTTONSEED OIL.

June 19, 1913, a calf was treated with 10 per cent oil of citronella in cottonseed oil, applied with an atomizer. A few hours later all protection had ceased.

July 2, 1913, the above calf was again sprayed. An hour or so later a repellent action was still noticeable. The calf was not troubled much with flies as compared with the untreated animals.

July 3, 1913, a cow was sprayed. Used 1½ ounces. There was a very marked repellent action, but an hour or so later this had become greatly reduced. There was a very slight odor of citronella at that time.

July 10, 1913, applied the mixture to a cow by means of a brush. Used about 6 ounces of oil. July 11, about 22 hours after application, oil was present on the neck and along the back. There was no odor of citronella. There was little or no protection as indicated by the presence of many hornflies on the underside of the abdomen, and the presence of many stable flies on the legs.

It is noted from the above tests that the mixture used is a powerful repellent, but that its effect does not last more than a few hours.

TEN PER CENT OIL OF SASSAFRAS IN COTTONSEED OIL.

June 19, 1913, a mixture of 10 per cent oil of sassafras in cottonseed oil was applied to a calf by means of an atomizer. There was a pronounced repellent action which, however, had disappeared at the end of a few hours.

July 2, 1913, the same calf was again treated. An hour or so later a repellent action was still present. The calf was troubled very little with flies as compared with the other animals. July 3, there was no odor or protective action noticeable.

July 3, 1913, treated a cow with the mixture. Used about 3 ounces. The repellent action was marked. An hour or so later the repellent action was greatly reduced and there was no odor of sassafras.

July 10, 1913, applied the mixture with a brush to the above cow. Used about $5\frac{1}{3}$ ounces. July 11, about 22 hours later, a little oil was present on the neck, withers, and just behind the withers. Many hornflies were present on the front legs and on the underside of the abdomen.

The above tests show that the mixture has a marked repellent action, but that this only lasts for a few hours.

TEN PER CENT OIL OF CAMPHOR IN COTTONSEED OIL.

June 19, 1913, a mixture of 10 per cent oil of camphor in cottonseed oil was applied to a calf by means of an atomizer. A few hours afterward some protective action was still noticeable.

July 2, 1913, the same calf was again treated. An hour or so later the calf was still protected from flies.

July 3, 1913, no protection was noticeable in the case of the above calf. A cow was sprayed with the mixture. Used $2\frac{1}{3}$ ounces. There was a marked protective action. An hour or so later the protective action was greatly reduced. There was no odor of camphor.

July 10, 1913, applied the mixture to the above cow with a brush. Used 5 ounces. July 11, about 22 hours after application, a little oil was present on the neck and along the back. There was no odor of camphor. Some hornflies were present and many stable flies were on the legs.

The immediate protection rendered by the above mixture is marked, but its action lasts only for a few hours.

HALF-AND-HALF MIXTURE OF KEROSENE AND COTTONSEED OIL.

August 7, 1913, a cow was treated with a half-and-half mixture of cottonseed oil and kerosene. The mixture was applied with a brush. The flies were repelled.

August 8, the oil was rubbed off the sides, abdomen, and the outside of the thighs. Very few flies were present.

KEROSENE EMULSION.

August 21, 1913, treated a cow with kerosene emulsion made according to the formula on page 11, diluted 1 to 8. The emulsion had only a very slight repellent action.

BEAUMONT OIL.

August 7, 1913, a calf was treated with Beaumont oil. The oil was applied with a brush. The repellent action was marked. August 8, the oil had been rubbed off the abdomen, the sides, and the outside of the thighs. Stable flies were present on the legs. There was plenty of oil present on the neck, shoulders, and back. There were no hornflies on the animal, although they had been numerous the day before.

FISH OIL.

July 22, 1912, a calf was sprayed with fish oil. About 2 quarts of the oil were used. July 23, the oil was present on the hair. Flies frequently lit on the animal but left almost immediately. A few stable flies were noted on the legs. No hornflies were observed.

July 25, considerable oil was still present. Some flies were seen to light on and crawl over the greasy hair. There was a very slight fishy odor.

July 29, oil was present on the back and rump. No hornflies were observed. Stable flies were observed on the legs.

August 6, rear portion of body very sticky and dirty. There was a loss of hair in spots on the back and sides.

July 15, 1913, applied fish oil with a brush. The protection was very marked. July 16, about 20 hours later, there was an abundance of oil present on the upper half of body, and a repellent action was noticeable in this region. There was still a very slight amount of oil on the legs, but it was not sufficient to keep the flies off.

In the first test with fish oil the oil was applied by means of a spray pump. Two liters were used. The repellent action lasted between one and three days. The liberal application of the oil caused the hair to become sticky and dirty in places. There was also a loss of hair. These unfavorable results were not noted in the second test, in which a light application of oil was made with a brush.

LAUREL OIL.

June 19, 1913, a calf was rubbed with laurel oil. The protection was very marked.

July 2, 1913, the oil was applied to a calf with a paint brush. There was a very marked repellent influence on both the hornflies and the stable flies. An hour or so later the repellent action was only very slightly reduced.

July 3, 1913, the same calf was treated. Used about 2 ounces. The mixture was applied with a paint brush. The repellent action was marked.

July 10, 1913, applied the oil with a brush to all parts of the body except the head. Used 5 ounces. July 11, about 22 hours later, there was an abundance of oil present on body and neck. There were no flies on the body and neck. Some stable flies were present on the legs.

July 15, 1913, a severe exfoliation was noted on the shoulders and neck. There was a slight exfoliation on the head. A similar exfoliation was noted on the withers shortly after the first treatment on June 19.

August 19, 1913, a calf was treated all over with laurel oil. Application was made by means of a brush.

August 20, there was an abundance of oil present. It was rubbed off the abdomen. The repellent action was marked, but the odor of the oil was not as strong as at first.

August 21, some oil was present on the back and sides. There was a repellent action still evident.

August 7, 1913, a cow was treated with 10 per cent laurel oil in cottonseed oil. The mixture was applied with a brush. The repellent action was marked.

August 8, oil was present on the neck, shoulders, and back. It was rubbed off the sides and abdomen. There was no odor of laurel oil. Stable flies were present on the legs. Hornflies were present on the abdomen where the oil had been rubbed off.

Laurel oil has a very marked repellent action on both hornflies and stable flies. No observations were made to determine the limit of the duration of the repellent action, but it undoubtedly as a rule continues for several days. On account of the fact that the oil has a tendency to produce an exfoliation of the skin it should be applied very lightly to the hair. As indicated by the last test, in a 10 per cent mixture of laurel oil and cottonseed oil the laurel oil disappears by evaporation in less than 24 hours.

PYRETHRUM POWDER.

July 25, 1912, a cow was dusted with pyrethrum powder along the neck and back. Used about 2½ ounces of powder. Flies were observed to light frequently on the treated portions of the body and remain for a time.

July 26, an attendant reported that there was plenty of powder still present and that it seemed to repel the flies.

August 9, 1913, pyrethrum powder was applied to the skin of a cow. The repellent action was very marked. August 10, only a very slight protective action was noted.

Pyrethrum powder when applied to the skin of cattle has a very marked repellent action, but this lasts only for about a day.

SUMMARY OF EXPERIMENTAL TESTS.

The experimental tests are summarized in the following table:

Summary of experimental tests.

Substance used.	Duration of odor.	Duration of repellent action.	Duration of presence of substance.	Method of application.	Effect on animals.
	Days.	*Days.*	*Days.*		
10 per cent crude carbolic acid in cottonseed oil.				Spray pump.	Phenol poisoning.
Do				do	Do.
Do	1+	1−	1+	Brush	None.
10 per cent pine tar in cottonseed oil	2−	3+	5−	Spray pump.	Caused depression.
20 per cent pine tar in cottonseed oil	1−	1−	1+	Brush	None.
50 per cent pine tar in cottonseed oil	3+	3+	3+	Spray pump.	Do.
Do	3+	3+	3+	do	Do.
50 per cent pine tar in Beaumont oil	2−	2−	2+	Brush	Caused stiffness.
10 per cent oil of tar in cottonseed oil	3−	3−	3+	Spray pump.	None.
Do	1−	1+	1+	Brush	Do.
50 per cent oil of tar in cottonseed oil		4−		Spray pump.	Phenol poisoning.
10 per cent oil of tar in Beaumont oil			7+	do	None.
Do	1−	1+	1+	Brush	Do.
50 per cent oil of tar in Beaumont oil	1+	2	2+	do	Slight symptoms of poisoning. On second day animal was stiff.
The Moore formula	3+	3+	3+	Sprayed	Phenol poisoning.
Do				Brush	None.
10 per cent oil of citronella in cottonseed oil.		1−		Atomizer	Do.
Do	1−	1−	1+	Brush	Do.
10 per cent oil of sassafras in cottonseed oil.		1−		Atomizer	Do.
Do	1−	1−		do	Do.
Do		1−	1+	Brush	Do.
10 per cent oil of camphor in cottonseed oil.		1−			Do.
Do	1−			Atomizer	Do.
Do	1−	1−	1+	Brush	Do.
50 per cent kerosene in cottonseed oil		1+		do	Do.
Beaumont oil	1+	1+	1+	do	Do.
Fish oil	3+	3−	7+	Spray pump.	Slight loss of hair.
Do				Brush	None.
Laurel oil	1+	1+	1+	do	Severe exfoliation.
Do	2+	2+	2+	do	None.
10 per cent laurel oil in cottonseed oil	1−	1+	1+	do	Do.
Pyrethrum powder		1+	1+		Do.
Do		1+	1+		Do.

GENERAL SUMMARY.

The biting flies that annoy domestic animals most in this country are the stable fly, *Stomoxys calcitrans*, and the hornfly, *Lyperosia irritans*. The bot flies are not biting flies, but are a menace to domestic animals because of the parasitic habits of their larvæ. This is also the case with the screw-worm fly, *Paralucilia macellaria*, which deposits its eggs in wounds, and a bluebottle fly, *Lucilia sericata*, occurring in the United Kingdom and Holland, and certain species of Calliphora occurring in Australia, the larvæ of which invade the wool and skin of sheep.

Repellents are more or less effective against all of these flies.

Opinions differ with regard to the injury by biting flies. The common opinion seems to be that these flies are responsible for great losses. However, a limited amount of experimental evidence relating to cattle seems to indicate that the losses, when they occur, are not great.

The repellent action of certain colors has been noted by various investigators. Light-colored animals suffer less from flies than dark-colored ones. One author (Marre, 1908) has recorded the observation of a farmer in France who found that a blue color applied to the inside of stables repelled flies. This observation seems to have remained uncorroborated.

Potassium tellurate has been recommended by Ochmann (1911) as an internal remedy for repelling flies. However, Mayer (1911) failed to obtain results with the remedy, and it seems safe to assume that internal remedies will never prove practicable in repelling flies.

Liquid repellents may be applied by means of a dipping vat, a pail spray pump, an atomizer, or by means of a rag or a paint brush. The method to be employed depends on the individual preference of the farmer and the nature and cost of the preparation used.

The powder remedies that have been used are pyrethrum powder and tobacco powder.

Various oils, emulsions of oils, and mixtures of oils are used in repelling flies. Crude petroleum, cottonseed oil, fish or train oil, and light coal-tar oil may be used pure. Jensen (1909) recommends for dairy cows an emulsion of crude petroleum containing an admixture of powdered naphthalin.

Fish oil is rated as one of the best repellents and has been used alone and in combination with various other substances. Other substances that have repellent qualities and that have been used in various mixtures are pine tar, oil of tar, crude carbolic acid, oil of pennyroyal, and kerosene.

Jensen's formula is said to protect cows for a week. The protective action of fish oil is stated to range from less than two days

(Parrott, 1900) to six days. Moore's formula is said to protect for two days. This mixture is safe when applied lightly with a brush, but not when applied liberally with a pail spray pump.

Laurel oil is a very effective repellent. Mayer (1911) found that the protection lasted from 2 to 12 days. The oil when used pure has an irritating effect unless it is applied lightly. According to Mayer the irritating effect may be overcome by combining it with linseed oil in the proportion of 1 to 10. The present author found that 10 per cent of laurel oil in cottonseed oil was active for less than a day.

A number of formulas for repellents for application to wounds have been recommended by various authors.

In experimental tests carried out by the present author the following results were obtained:

A 10 per cent mixture of crude carbolic acid (21.8 per cent phenols) in cottonseed oil has a very strong repellent action on flies, but this lasts less than a day, in consequence of which it is necessary to apply the mixture every day. The mixture should be applied lightly with a brush, since a heavy application with a spray pump is likely to cause phenol poisoning.

Mixtures consisting of 10, 20, and 50 per cent of pine tar in cottonseed oil have marked repellent qualities. They should be applied lightly and it is necessary to apply them every day. A liberal application of a 10 per cent mixture is deleterious to animals. This is also the case with a half-and-half mixture of pine tar and Beaumont oil when applied lightly with a brush.

A mixture of oil of tar (14 per cent phenols, volatile with steam) in cottonseed oil and in Beaumont oil has a very marked repellent action. A 10 per cent mixture of oil of tar in cottonseed oil is safe. A half-and-half mixture of oil of tar and cottonseed oil when applied liberally with a spray pump and 50 per cent oil of tar in Beaumont oil applied with a brush are not safe. Ten per cent oil of tar in Beaumont oil is safe. When applied lightly it is necessary to apply 10 per cent oil of tar in cottonseed oil or 10 per cent oil of tar in Beaumont oil every day.

Mixtures of 10 per cent of oil of citronella, oil of sassafras, or oil of camphor in cottonseed oil are powerful repellents, but they are active for less than a day.

A heavy application of fish oil causes the hair to become sticky and fall out. A light application did not produce these results.

Pyrethrum powder is an effective repellent, but its action lasts only for about a day.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 132

Contribution from the Office of Experiment Stations, A. C. True, Director.
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CORRELATING AGRICULTURE WITH THE PUBLIC-SCHOOL SUBJECTS IN THE SOUTHERN STATES.

By C. H. Lane, *Chief Specialist in Agricultural Education* and E. A. Miller, *Assistant in Agricultural Education.*

PURPOSE OF THE BULLETIN.

The club movement that is taking hold of the young life of our country promises to afford the teacher a most potent means of vitalizing the everyday work of the school. The problems of securing the interest of the pupil in the common-school branches, of teaching in an effective way farm economy, and of gaining the abiding interest of the school patrons seem to have in a large measure their solution in the correlation of agriculture with the common-school branches by means of boys' and girls' clubs. It is the purpose of what follows to suggest some ways and means by which the rural or public-school teacher may utilize clubs in correlating agriculture and farm-life problems with the regular school work.

In setting forth this correlation scheme the public-school classes are divided into two groups, the first group including grades one to five, and the second group including grades six to eight. This division is made for two reasons. In the first place, very few active club members will be found in the first group of grades, and the club influence in correlating the work with them will be largely incidental, while with the second group, in which most of the club membership will be found, the influence should be direct. In the second place, the incentives that stimulate pupils of the ages usually found in the first group are quite different from those that affect the pupils found in the second group. That is to say, pupils below the age of 12 are influenced more by imaginative and cultural stimuli, whereas pupils above that age and usually found in the sixth, seventh, and eighth grades are appealed to more strongly by economic incentives.

Note.—This bulletin is prepared especially for the use of rural school teachers in the Southern States.

THE PLAN.

The term "correlation" as used in this publication means nothing more nor less than leading pupils into the interpretation of their public-school studies by using things most familiar to them, such as farm, home, and school-life facts and incidents.

It will be observed that the material is arranged according to a monthly sequence plan. Nine months' work is provided for, but in case the school term is not so long, as is generally true in rural schools, the work out of season may be dropped. Any feasible work suggested for months before or after the opening and closing of a school should be undertaken at seasons best suited to the local conditions.

As suggested by the title of this publication, the correlation scheme is intended to be adapted to the southern section of the United States. Covering, as it does, a large territory, the scheme must be of necessity largely suggestive. The details, such as the statement of problems, working of subjects in language exercises, etc., should be left to the teacher. The gathering of local data as the basis of work should be intrusted in a large measure to the club members of the school. This is a point at which the teacher can secure the cooperation and interest not only of the pupils but of the patrons as well. When it is manifested that the school is to use the community problems and facts as the basis of its exercises there will be an awakening in school interest that will probably surprise even the teacher.

HOW THE TEACHER MAY ORGANIZE A CLUB.

As soon as possible after the school opens in the fall the teacher should write the county superintendent and the State agricultural college for all printed matter available pertaining to agricultural clubs. When the teacher has studied the literature and has become familiar with the plans, projects, rules, etc., of clubs, a meeting for organization should be called and should include as many boys and girls of the school district as can be brought together. It would be well to invite the patrons of the school to this meeting and have the farm-demonstration agent for your county give a talk on the agricultural-club movement. If possible, have your county superintendent of education and the woman in charge of girls' canning clubs at this meeting and ask their aid in this organization work. Near the close of the meeting, which should not be too long, a simple form of constitution and set of by-laws may be adopted, and the regular officers of the club elected at this time may include a supervisor, president, vice president, secretary, treasurer, and program committee.

The following general form of organization has been found satisfactory:

Suggested Constitution and By-laws.[1]

CONSTITUTION.

Article I. *Name of club.*—This organization shall be known as .... School Boys' and Girls' Agricultural Club.

Art. II. *Objects of club.*—The objects of the club shall be to make farm life more attractive and farming more profitable.

Art. III. *Membership.*—Boys and girls from 10 to 18 years of age shall be eligible.

Art. IV. *Officers.*—The officers of this club shall be a supervisor, president, vice president, secretary, and treasurer.

Art. V. *Duties of members.*—Prescribed in the rules for contests, such as follow instructions, attend club meetings, make exhibits at the school and county fair, and keep a report of expenses, income, observations, and work.

Art. VI. *Duties of officers.*—The president shall preside at all meetings; the secretary shall keep the minutes and records of all such meetings; the treasurer must care for all funds collected and shall pay out the same only upon the written order of the president, and the vice president may act as president in the absence or disability of that officer. The teacher shall be supervisor, having the general supervision of all local club work and power of exercising authority in proper management of the club.

Sec. 1. An advisory committee shall arrange for all public contests and exhibits, the procuring and awarding of prizes, and the reporting of statistics and other information to the State organizer.

BY-LAWS.

1. The members of the club shall agree to read all reference literature bearing upon the home project. This may include literature dealing with the growing of corn, cotton, potatoes, tomatoes, chickens, pigs, etc.

2. A written plan of the work of each boy and girl must be prepared for the teacher. They must do all the work connected with the particular contest or project entered upon.

3. The amount of yield by weight and measurement of land and other results of the spring and summer work must be certified to by the contestant and attested by at least one disinterested witness, preferably a member of the local school board.

4. Every member of the club must make an exhibit at the annual school fair.

5. In estimating profits, $5 per acre shall be charged as rent of land. The work of each club member shall be estimated at 10 cents per hour, and the work of each horse at 5 cents per hour. Manure shall be charged at the rate of $1 for each one-horse wagonload and $2 for each two-horse wagonload.

6. No club member will be allowed to receive more than two prizes.

7. The committee of judges for the annual school fair shall be selected by the teacher.

8. Exhibits winning prizes at the school fair should be sent to the annual county contest and even to the State contest.

9. All awards on farm crops shall be based upon the following score:

	Per cent.
(a) Greatest yield per acre	30
(b) Best exhibit	20
(c) Essay and report	20
(d) Best showing of profit on investment	30
Total	100

[1] The teacher should write the State agent in charge of club work at the State agricultural college for suggestions concerning the organization and conducting of a boy's and girls' agricultural club.

PRIZES.

The matter of prizes is of great importance. While the various contests of the club members have for their primary object the assistance of the teacher and the public schools to find an easy approach, educationally, to all the interests of rural and village life and to form a connecting link between parent and teacher, farm, and school, it is found that prizes are necessary to secure the best results. An attempt should be made to offer a large number of prizes. Among the prizes suggested by the Bureau of Plant Industry as suitable awards in club contests, the following may be mentioned:

(1) Free trips and expenses paid to district and State fairs, educational institutions, summer Chautauquas, etc.
(2) Top buggy, saddle, gold watch, automobile, etc.
(3) Clear title to one or more acres of land (to encourage land ownership).
(4) Farm implements, tools, equipment, etc.
(5) Thoroughbred pigs, cattle, horses, mules, pen of chickens.
(6) Club emblems, banners, and pennants.
(7) Manual-training workbench, set of toools, camera, trunk, leather handbag, writing desk, etc.
(8) Poultry equipment, such as incubators, watering and feeding troughs, brooders, fencing, and gates.
(9) Free tuition to short courses in agricultural and mechanical colleges and regular courses in colleges.
(10) Canvas tent, camp outfit, canoe, hunting equipment, baseball suit, and suit of clothes.
(11) Dictionary, encyclopedia, set of agricultural books, special club library, series of books of standard literature.
(12) Subscriptions to farm journals, magazines, and special periodicals for boys.

School credit should be given to every member of the club who carries to completion some one club project. Every boy and girl should be taught the real meaning and value of a prize and that a realization of work well done is the true reward of effort.

HOW TO KEEP UP THE CLUB INTEREST.

The success of the rural school club depends largely upon the cooperation of the rural school teacher, county superintendent of education, farm-demonstration agent, and the State college of agriculture. Shortly after the club is organized in any rural school the teacher should submit the names of the members to the county superintendent of education, who will assist in furnishing the club with literature directing them in the work. The teacher will find it advantageous to have the county demonstration agent make talks before the school, as well as visit the contestants' home projects as he makes his rounds from time to time. The teacher should visit the homes of all club members and, together with the boys and girls and any other members of their families, go to the prize acres, etc., and have the owners tell the methods of preparing the soil, fertilizing, and thus far cultivating the crop. The results of such a trip will present much material for discussion at club meetings and regular class instruction in agriculture. For every school club there should be a local committee of three men and three women who will encourage the children, interest influential members of the community in the club, and inspect from time to time the work of the club.

THE SCHEME FOR GRADES ONE TO FIVE.

In following the scheme for the first five grades it is suggested that as much practical work as possible be done in nature study and in the school and the home gardens. As many as possible of the facts for the various exercises should be secured from these two sources. If junior agricultural clubs are organized in the school the members should be able to render valuable service in making the correlation work successful.

SEPTEMBER.

LANGUAGE LESSONS.

To develop the conversational powers of the younger children the language-lesson work may be supplemented by engaging them in conversation and putting tactful questions to them concerning the conditions of crops and the home-life problems. These are facts with which the children may readily familiarize themselves and concerning which they will feel free to speak.

Slightly more advanced pupils may be exercised in relating stories concerning the home and the farm. The more advanced pupils of this group should be required to reduce their narratives to writing and unconsciously engage in composition work. Written descriptions of things seen on the monthly excursions to the woods and fields should be required.

READING AND SPELLING.

The following are suggested for supplementary work in reading during this month: The Hay Loft, R. L. Stevenson; Milking Time, Christina Rossetti; September, Helen Hunt Jackson; The Village Blacksmith, Longfellow; The Country Boy's Creed, Edwin O. Grover; Solomon and the Bees, John G. Saxe; The Story of a Leaf, Rebecca Rickoff; and Garden Plants, A. B. Alcott. The adaptation of the foregoing to the different classes must be left to the teacher. Most of these articles will be found in any good system of public-school readers.

The words in the supplementary work for the month having an agricultural bearing should be listed and assigned as lessons from time to time. The difficulty of any assignment should depend upon the advancement of the class. In the supplementary work of this month, for example, will appear such words as follow: Apple, juice, core, tree, leaves, limbs, peanut, ground pea, pindar, goober, vine, nodule, root, drill, seed, grain, potato, eyes, tomato, cotton, square, bloom, tobacco, acre, yield, stalk, fodder, ears, tassel.

DRAWING.

Simple outline work of the various leaves found in the school or home garden, and parts of the plants and the fruit of the same should be done by pupils this month. Drawings of some of the simpler insects found in the garden, orchard, and fields should also be made. Adapting the work to the advancement of the pupils must be left to the judgment of the teacher.

HISTORY.

Have the pupils learn from whatever source available the history of the plat of ground occupied by the school building. In this connection have them give an account of the school buildings that have been used by the school district in the past. Such points as where they were, when built, and by whom should be covered by the account. Have the pupils also collect facts as to the principal school activities of the past, as to the teachers employed, their terms of service; as to the clubs organized, the prizes won, and the names of the winners.

GEOGRAPHY.

Have the smaller pupils prepare a sketch showing the outlines of the school ground, the location of the building, and the principal equipment in the building, the location of the trees, the playground, the school garden, walks, etc. Let the more advanced pupils follow this up with a study of the school district with regard to the location of the different crops grown. The pupils of the fourth and fifth grades should extend this work to the county. Outline maps should be prepared showing the location of the different crops grown and how the growth is affected by the character of soil and its topography. To indicate the crops grown and the location of other agricultural enterprises the outline map of the county should be filled in with seeds, pictures of animals, fruits, etc.

ARITHMETIC.

For the beginners the simple processes of counting, addition, subtraction, etc., should be taught by using the agricultural products of the school garden and the fields, such as apples, peas, small grains, potatoes, etc. Determining the number of peas in a pod, in a pint measure, and estimating the number in a bushel; estimating the number required to plant an acre, either broadcast or in the drill, will give exercises for these processes. Similar exercises may be developed in connection with the other products mentioned. Exercises for more advanced pupils may be secured on excursions to the fields by taking measurements and counting the number of plants within the area taken and, with this as a basis, determining the number of plants per acre. By counting the number of ears of corn, bolls of cotton, fruits, or seeds of other crops within the area taken, the yield per acre may be estimated and the size and value of the crop determined. Such exercises may be multiplied almost indefinitely.

EXCURSIONS AND PRACTICAL WORK.

Weekly excursions with the pupils should be made to near-by fields, orchards, and forests with a view of gathering facts for the language and arithmetic exercises and making observations for the geography work.

Practical work in gathering school-garden products and caring for the fall crops should be done. Collecting, grouping, and mounting helpful and harmful insects should be engaged in.[1]

OCTOBER.

LANGUAGE LESSONS.

Conversations with younger pupils about the progress being made on the farms in harvesting crops should provide supplementary work for them. Brief written statements concerning their observations at home should be required. Of pupils of more advanced classes, narrations concerning their observations in connection with methods employed in harvesting should be required. After the stories have been related orally in class the pupils should be required to reduce them to writing. The more advanced pupils should write stories and descriptions concerning observations on excursions.

[1] See U. S. Dept. Agr., Farmers' Bul. 606.

READING AND SPELLING.

The following are suggested for supplementary work in reading during this month: The Kitten and the Falling Leaves, Wordsworth; Evening at the Farm, J. T. Trowbridge; The Corn Song, Whittier; That Calf, Alice Cary; Autumn Leaves, George Cooper; Autumn, Edmund Spencer; Farmyard Song, J. T. Trowbridge, and Harvest Song, James Montgomery.

List and assign the new words bearing on agriculture found in the correlating exercises of this month. The following are suggested as examples of words that will appear: Variety, crib, soil, plat, test, report, visit, fair, pumpkin, exhibit.

DRAWING.

The following are suggested for outline work in drawing: Ears of corn, grains of corn, open cotton boll, pumpkins, potatoes, and other field and garden products in season.

HISTORY.

Have each pupil, sufficiently advanced to do so, prepare a history of his homestead or place at which he resides, dating back as far as reliable information may be had. Special mention should be made of the farm improvement, the character of the crops grown and with what success, and the connection the home and the people have had with the agricultural and school development of the community.

GEOGRAPHY.

Have the younger pupils prepare an outline of the farmstead showing location of the house, outbuildings, garden, and orchard. Require them to use seeds and pictures to indicate the location of the permanent objects on the farm and to indicate the farm products and animals grown.

Have the older pupils study the yields of the crops of the community as affected by elevation and character of soil. Let it be shown in each case where there are striking examples of good or poor yields whether it is due to the elevation or to the character of the soil.

Require the more advanced pupils of this group to plat a 5-acre piece of ground, locating the trees, streams, hills and hollows, houses, if any, crops grown, relative yields, and the different kinds of soil.

ARITHMETIC.

For the simpler processes with the younger pupils use shelled peanuts, finding the number of peas in a pod of each variety, the number in a pint, and estimate the number required to plant given areas. Determine the number of rows of grain on an ear of corn, the number of grains in a row, and the whole number of grains on the ear. By using specimens of different varieties these exercises may be multiplied to meet the needs of the work. Similar processes with cotton seed and other garden and field crops may be developed. For more advanced pupils simple processes in the cost of material for farm buildings may be used.

EXCURSIONS AND PRACTICAL WORK.

Weekly trips to near-by fields for the purpose of observing methods of harvesting crops and seed selection should be made. In most sections of the South October is the month for county fairs. By all means let the teacher spend at least one day with his pupils at the fair for the purpose of studying the exhibits and taking notes. The agricultural exhibits at the fair should prove a source of splendid material for correlation exercises.

Seasonable work in the school or home garden should constitute the practical work of the month.

NOVEMBER.

LANGUAGE LESSONS.

The farm stock, poultry, and implements, the roads to school, to church, and to the local market should provide material for conversation for the younger pupils. For the slightly more advanced pupils oral and written narrations on the foregoing subjects should be required. For the still more advanced pupils written descriptions of different breeds of poultry and stock and the farm implements should constitute the work. The condition of the roads to the county courthouse and to the principal county market should also provide material for written work.

READING AND SPELLING.

The following are suggested for supplementary work in reading for this month: November, Alice Cary; How the Leaves Come Down, Susan Coolidge; The Flight of the Birds, E. C. Stedman; Hunting Song, Coleridge; Cotton, Zitella Cocke; The Farmers' Gold, Edward Everett; Indian Corn, Edward Eggleston; and To a Mouse, Robert Burns.

List and assign the new words that appear in the correlation work of this month. Among these should be found such as follow: Poultry, chicken, duck, goose, turkey, egg, feathers, color, horse, swine, sheep, breed, calf, roads, market, produce, progress.

DRAWING.

Drawing for this month should consist of outlines of eggs, different kinds of poultry, farm animals, simple farm implements, split-log drag, etc.

HISTORY.

A history of marketing the community crops should be prepared consisting of such items as the following: Places at which sold, prices obtained, manner of transporting, condition of roads, cost of marketing, etc. For the more advanced pupils of this group a history of the methods of county road working, past and present road laws, should be studied. The extent to which the growing of crops in the different parts of the county has been affected by roads should be studied. A comparison of the home county with adjoining counties where conditions are better or worse should be made.

GEOGRAPHY.

A study of the effect of elevation on the maturing of crops should be made in the school district and in the adjoining districts. The excursions for this month should be made to include observations of fields of different elevations to note the effect. A study should be made also of the influence of elevation on the kinds of crops that the community is able to grow. This study should be extended through the county and to the adjoining counties for the benefit of the more advanced pupils.

ARITHMETIC.

A profitable exercise for beginners is to have them count the number of farm implements, stock, poultry, and things of like character at their homes and report the same to the teacher in class. By finding totals of each variety or class and of all farm animals and implements many exercises may be developed. For the more advanced pupils problems as to the cost of marketing crops on good and bad roads, taking into account the time, the size of the loads, and the life of wagons should be developed. Problems on the effect of good and bad roads on the price of land should be made. As a basis for these exercises values in different communities where roads are good or bad should be taken into consideration. It would be well during this month to develop problems on the cost of planting fruit trees and the value of their yields.

EXCURSIONS AND PRACTICAL WORK.

The excursions for the month will be determined more or less by the correlation needs. Special attention should be given however to visiting farms of the community having improved breeds of poultry and swine. Where possible, excursions should be made to farms equipped with modern implements, and the names and uses of these implements learned. If there is no farm in the community affording this opportunity, a visit to an extensive hardware concern for this purpose should be made. Farm-supply catalogues should be ordered, and the names of farm implements and their uses learned.

Seasonable work in the school garden should be done. Cuttings of shrubbery and fruits should be made and stored during this month.

DECEMBER.

LANGUAGE LESSONS.

For the younger pupils conversations on corn and its uses, cottonseed and its by-products and uses, peanuts, peas, and the small grains and their uses should be engaged in. Oral and written narrations on visits to old-fashioned gins, water mills, and other out-of-date machinery should be required of the more advanced pupils. Written descriptions of old-fashioned looms, spinning wheels, mowing blades, etc., compared with the modern machinery substituted for them should also be required.

READING AND SPELLING.

The following selections are suggested for supplementary work this month: The First Snow Fall, Lowell; and The Origin of Roast Pig, Charles Lamb. For the younger pupils there are a number of interesting Mother Goose rhymes relating to agricultural subjects that may be used.

List and assign the new agricultural terms found in the correlation work as spelling exercises for this month. As examples of words that will appear the following are submitted: Starch, meal, bread, flakes, oil, gin, wheel, machine.

DRAWING.

During this month it will be profitable to engage the pupils in drawing all kinds of farm-crop seed and weed seeds and learning to recognize them at sight. It will be interesting to introduce colored crayons at this time to give each seed as nearly as possible its shade of color.

HISTORY.

It is suggested that during this month the history of the methods of planting, cultivating, harvesting, and marketing of the ordinary crops be studied. This study should tend to bring out the improvement that has been made in the various methods.

GEOGRAPHY.

During this month the study in geography should relate to the crops that are kept on the farm and those that are sold, the agricultural products that are bought by the community and the crops exchanged for them. The reason for the exchange of these crops should be noted, and the loss or gain to the community by the same. The means of exchanging crops should be studied, such as the manner of transportation and the commercial concerns engaged in buying and selling.

ARITHMETIC.

For the younger pupils exercises in determining the number of eggs, pounds of butter, and gallons of milk produced at each home in the community and the value of the same during each week in December should be developed. For the more advanced pupils problems involving the following items of farm management should be developed and assigned: Harvesting, preparing for market, the cost of marketing, the cost of feeding poultry flocks, the cost of feeding dairy cows, the value of their products, and the per cent profit or loss.

EXCURSIONS AND PRACTICAL WORK.

Excursions should be made with a view of making comparison of old and out-of-date and new farm machinery, gins, grain mills, etc.

During the month of December indoor exercises in studying and learning to identify seeds of plants and weeds, and learning to distinguish between good and bad seeds should be practised.

JANUARY.

LANGUAGE LESSONS.

Conversations concerning the uses of fertilizers, the quantity required, and for what crops, should be engaged in with the younger pupils. Oral and written accounts of visits to fertilizer plants, methods for distributing fertilizers, and methods of mixing should be required of the more advanced pupils of the group. Descriptions of fertilizer distributors, fertilizer mixing boxes, and the different brands of fertilizers should constitute work for the still more advanced pupils of this group.

READING AND SPELLING.

The following selections are suggested as supplementary work for this month: Winter Time, R. L. Stevenson; The Snowdrop, Tennyson; The Frost Spirit, Whittier; and Snowbound, Whittier.

List and assign words found in the correlation exercises of this month adapted to the use of the several classes. Among this number should be found such as follows: Sacks, brand, potash, acid, nitrogen, mixed, material, fertilizer, community, distributor, commercial, elements, manufacture, formula, problem, profit.

DRAWING.

The drawing work of the month should consist of outlines of fertilizer sacks, fertilizer horns, fertilizer mixing boxes, tools employed in home mixing of fertilizer, and sketches of more improved fertilizer distributors.

HISTORY.

Study the history of the use of commercial fertilizers in the community and county, noting the principal brands and formulas that have been used and in connection with what crops. Let special attention be given to the effect that the use of fertilizers has had upon the agricultural development of the community, noting the crops grown previous to the use of fertilizers and those grown since their use. Also study the effect of fertilizers on the yield of crops. The development of the industry of manufacturing fertilizers in the community, county, and State should be studied, and in connection with this the history of the prices and the conditions that have affected prices.

GEOGRAPHY.

Study the leguminous crops that can be grown in the community successfully, noting the locality and the conditions obtaining. Extend this study to the county, noting where the leguminous crops are grown and not grown and the reason. Locate the fertilizer plants in the community, county, and State, and assign reasons for the particular location. What and where are the raw fertilizer materials found in the community, county, and State? What crops are exchanged for fertilizers, and is the exchange made at a profit or loss?

ARITHMETIC.

Have the younger pupils count the number of sacks of fertilizer used at home and report this to the teacher. Let the total number of sacks be determined, the total number of pounds for each farm, for the community, and find the average number of pounds used per acre for each farm and for the entire community. Multiply this work to include the cost per acre, per farm, and for the community. For the more advanced pupils develop simple problems on the cost of fertilizing elements taken from the soil by each crop. Prepare statements of problems involving the replacing of fertilizing elements by leguminous and other cover crops and by the use of mold. Problems involving the cost of the elements in various fertilizers as determined by their formulas should be developed.

EXCURSIONS AND PRACTICAL WORK.

Visits to fertilizer plants, warehouses, etc., for the purpose of observing the mixing processes and of securing the names of the different brands, their formulas, and special uses, should be made. The necessary data for the other correlation exercises should be secured on these trips.

During this month the school grounds should be laid out and the year's work planned. The plats of the individual pupils in the school and home gardens should be laid out and located during this month. Making stakes and other devices to be

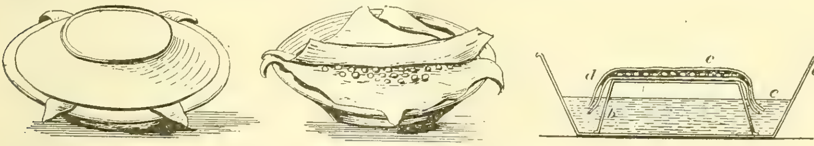

FIG. 1.—Simple seed-germinating devices.

used in the school and home gardens should constitute some of the practical work of the month.

FEBRUARY.

LANGUAGE LESSONS.

Conversations on the need, value, and methods of seed testing should be engaged in. For the slightly more advanced pupils oral and written narrations of the steps in making a seed-testing box should be required. Written descriptions of seed-testing boxes should be assigned as work for the still more advanced pupils. Conversations and oral and written statements concerning the value of sprays, the materials used, the steps in mixing, and the devices used, should be given. Descriptions of methods of pruning and grafting should constitute work for the advanced pupils of this group.

READING AND SPELLING.

The following selections are suggested for this month: The Oak Tree, Mary Howett; The Voice of the Grass, Sarah Boyle; The Planting of the Apple Tree, Bryant; Woodman Spare That Tree, G. P. Morris; The Parable of the Sower, The Bible; How to Plant a Tree, Julia E. Rogers; and Plant a Tree, Lucy Larcom.

Such words as the following will appear in the correlating exercises of the month: Seed, testing, checks, production, germination, diseases, insects, spraying, pruning, grafting, scion, stock, vigorous, tongue, cleft, budding, helpful, harmful.

DRAWING.

Make drawings of different kinds of seed testers (fig. 1), of germinating grains, both weak and vigorous, of diseased parts of plants showing affected parts, of proper and improper cuts in pruning, of different methods of grafting.

HISTORY.

The history of the practice of testing seed in the community and county showing the different methods employed, and the effect in crop production should be studied. A study of the different fruit crops of the community and county as to their introduction, success or failure, and why, should be made. The history of plant diseases and insects, showing how and when introduced and the successful and unsuccessful methods of combating them should constitute part of the correlation work of the month.

GEOGRAPHY.

The correlation work in geography for the month should consist in naming and locating the farmers of the community and county that have practiced seed testing. Name and locate the plant diseases that obtain in the community and county, setting forth the conditions favorable and unfavorable to the propagation of the same and the effect that the appearance of these diseases and insects have had upon the agricultural interests. What conditions of climate, altitude, and soil obtain favorable and unfavorable to fruit growing.

ARITHMETIC.

For the younger pupils work may be assigned involving the determining of the number of checks in seed testers, the cost in time and material of making them, and the value of the time spent in testing seed. For more advanced pupils problems should be developed involving the value of testing seed, the value of the time spent in such work, and the loss that would be sustained in poor stands by failure to do it properly. These processes may be multiplied to include as many principles of arithmetic as desired. Problems involving the cost of spraying mixtures, and the time employed in their application should be developed. The work should be extended to the saving in fruit crops and the value of the time and means expended in this way. Let your problems be based as nearly as possible upon local experiences.

EXCURSIONS AND PRACTICAL WORK.

Excursions should be made this month for the purpose of observing diseased orchards and learning to distinguish the different diseases affecting the plants of the same. Specimens of diseased plants and vegetables should be brought from the homes of the community for study in the school. Special attention should be given to the seeds that are to be planted in the school garden. As a matter of precaution all seeds should be subjected to preventive treatment in order that the school or home garden may not become infested with diseases.

The practical work of the month should consist of testing the vitality of seeds to be planted in the garden, pruning of school or home ground shrubbery, preparing ground, and planting early vegetables.

MARCH.

LANGUAGE LESSONS.

Have the younger pupils engage in conversation and prepare short written statements concerning the kinds of birds, their habits and their means of subsistence. Oral and written statements should be required of the more advanced pupils concerning the habits of birds, their means of subsistence, and migrations. These stories should be based on observations made on the school grounds and during excursions made to the fields and woods. Written descriptions of nests and their locations should be required of the more advanced pupils. Reasons should be sought and assigned for the nesting habits of different birds.

READING AND SPELLING.

The following are suggested as supplementary selections for the month: Little Birdie, Tennyson; Daisies, T. D. Sherman; Robin Redbreast, William Allingham; The Barefoot Boy, Whittier; Mary Emily's Chickens, L. N. Duncan; The Lamb, William Blake; The School Garden at Plumfield, Louisa M. Alcott; and The Botany Lesson, Rebecca Rickoff.

List and assign the new words of an agricultural bearing appearing in the correlation work of this month. Examples: Bird, nest, flock, migration, local, value, location, destroy, native, rodents, pests, insects, materials, garden, habit, domestic, prevalent, subsistence, stake, preparation, planting, practical.

DRAWING.

Simple outline work of birds, fowls, and different kinds of nests should constitute the drawing work of the month. In case of more advanced pupils, some color work with crayon might be required to give touches of reality to the sketches.

HISTORY.

Study the history of the birds prevalent in your community and section. This history should cover the origin, introduction (in case any of the birds are not native), and their relation to agriculture. Special attention should be given to the relation of the different kinds of birds to historical events, art, song, and story.

GEOGRAPHY.

Study the migration of local birds. Learn the conditions of climate and food supply at the places to which they go. Compare these with local conditions of the different seasons. Compare the habits and uses of migrating and nonmigrating birds, as to their methods of subsistence. Study the habits of nesting as to locality and assign reasons for the selection of different places by the different kinds of birds.

ARITHMETIC.

For the younger pupils, develop problems on the number and quantity of the different kinds of seeds, such as onions, potatoes, corn, beans, peas, etc., required to plant a given area. For the slightly more advanced pupils, a record of the time spent in working plats in the school or home garden should be kept and problems developed on the value of the time. For still more advanced pupils, problems on the cost of materials used in the home and school gardens, such as stakes, fertilizers, and seed, should be developed.

EXCURSIONS AND PRACTICAL WORK.

During this month, excursions should be made to the forests to observe the birds, to learn their names, their songs, their habits of nesting, means of subsistence, and other peculiarities. The same studies should be made with reference to the undomesticated animals, rodents, and insects prevalent in the community. This work should be extended through the months of March, April, and May.

Making hotbeds, germinating plants, preparing ground, and planting plats in the home and school gardens should constitute the practical work of the month.

APRIL AND MAY.

LANGUAGE LESSONS.

For the younger pupils, conversation practice and brief narrations, oral and written, concerning the school-garden experiences and insect, animal, and bird habits should be engaged in. For more advanced pupils, oral and written exercises concerning the preparation of seed beds, planting, fertilization, and cultivation should be required. The written work should be extended to descriptions of plants in process of germination and in different stages of growth. Oral and written stories on the rounds of economic insect life, the means of subsistence in each stage of existence, and the methods of combating insects in each stage of existence should constitute part of the written work for the month.

READING AND SPELLING.

The following are suggested for supplementary exercises: The Cow, R. L. Stevenson; The Little Plant, Kate Brown; Come Little Leaves, George Cooper; The Busy Bee, Isaac Watts; Little Cock Sparrow; The Bee and the Flowers, Tennyson; To a Butterfly, Wordsworth; The Gladness of Nature, Bryant; The Owl, Tennyson; The Song of the Brook, Tennyson; The Pet Lamb, Wordsworth; Sweet Peas, Keats; and To a Mountain Daisy, Robert Burns.

The new words and terms appearing in the correlation exercises of April and May should be listed and assigned as lessons from time to time. Examples, plantlet, leaves, roots, flowers, simple, stage, existence, elevation, drainage, excursion, combating, forests, germination, absorption, growth, implements, developed, common.

DRAWING.

The drawings of these months should consist of outlines and sketches of germinating seeds, plantlets, leaves, roots, flowers, and parts of flowers from the gardens, fields, and forests. Drawings of devices and simple implements used in the school garden should be made. Drawings of the insects found in the gardens, the home orchards, and the fields should also be made. Insects having a well-defined round of life should be studied with a view of making drawings of each stage of existence.

HISTORY.

The history of the most common garden plants covering the following points should be studied: Where native, by whom domesticated, or in case of varieties, by whom developed, and when and under what circumstances introduced into the community or section.

The life history of the prevalent insects, both beneficial and harmful, should be studied, giving special attention to when, where, and how they exist in each stage of the round of life; when, where, and how introduced into the community.

GEOGRAPHY.

The time of planting garden plants as affected by climate, elevation, and drainage in the community and in the local school garden should provide interesting work in the subject these months. Market gardening with a community bearing should be studied, noting especially the crops that can be successfully grown, the means of distribution, and the places of marketing. Such questions as follow should be answered: What garden products does your community buy, and why? Where were they raised, and what conditions obtained? What effect has the Girls' Canning and Poultry Club had upon the production of these products in your community? What effect have insects, fungus diseases, and birds upon the time of planting, the manner of cultivation, and the general treatment of garden crops?

ARITHMETIC.

Problems should be developed on the value of birds to the farmer in the number of weed seeds and insects destroyed by each individual bird in the course of a year. Estimates of the harm done by birds, rodents, vermin, insects, and small animals should provide material for exercises in arithmetic.

EXCURSIONS AND PRACTICAL WORK.

Excursions for the purpose of studying birds, animals, and insects should be continued. It would be well to make excursions to gardens, orchards, or fields where methods of combating harmful species of any of the foregoing are being employed.

Practical work for these months will consist almost entirely of caring for the garden plats of the pupils (fig. 2).

THE SCHEME FOR GRADES SIX TO EIGHT.

While the following suggestive scheme is prepared for all the pupils of these grades, yet the success with which these exercises may be correlated with the other school work will depend to a great extent upon the cooperation of the club members of the school. The im-

FIG. 2.—Harlem, Ill., consolidated school garden.

portance of club membership should be emphasized by the teacher in every way possible, especially by calling upon the members to assist in this work and by making the problems of the clubs the problems of the school.

SEPTEMBER.

LANGUAGE LESSONS.

Written reports of field observations. Compositions on selection of seed in the field: Corn, cotton, tomatoes, potatoes, tobacco, cane, peanuts, etc. Make records of practical work. Letter writing: Write letters ordering seed catalogues, asking for the quotation of prices on seed, requesting publishers to contribute farm papers for school libraries, asking friends and others to contribute books on agricultural subjects for school libraries.

READING AND SPELLING.

The following are suggested for supplementary correlation reading: Bureau of Entomology Circular No. 6, The Mexican Cotton-Boll Weevil; Bureau of Animal Industry Circular No. 208, Organization of Girls' Poultry Clubs; Bureau of Entomology Circular No. 4 (2d ser.), The Army Worm; Farmers' Bulletins Nos. 198, Strawberries; 290, The Cotton-Boll Worm; 303, Corn-Harvesting Machinery; 408, School Exercises in Plant Production; 415, Seed Corn; and 478, How to Prevent Typhoid Fever.

List and assign new words related to agriculture for spelling exercises.

DRAWING.

Make drawings of ideal and faulty specimens of various farm plants such as corn, cotton, sugar cane, tobacco, tomatoes, etc. Collect, name, and make drawings of weeds and helpful and harmful insects active at this season.

HISTORY.

During the month of September, or the opening month of school, considerable time should be spent in organizing the school clubs, studying parliamentary practice, familiarizing club members with rules governing contests, planning exhibits for the county fair or school fair, practicing club members in making out reports of yields, and planning and preparing the agricultural notebooks to be used by the pupils in keeping records of the ensuing year.

GEOGRAPHY.

Have each pupil prepare an outline map of the State and fill in with seeds, fibers, and pictures, showing by these the agricultural products of the State and their location as affected by climate. Extend this study to the other States and show by comparison of the agricultural products in what respects the climate is the same, and in what respects the climate is different from the local State. Follow this up with a study of the agricultural products of other countries for the purpose of determining those that have the same climatic conditions and those that differ.

ARITHMETIC.

Develop problems from measurements made of fields of given crops and especially club acres and plats. Count stalks, ears, bolls, etc., and with these as a basis develop exercises on yields, values of crops, etc. From data gathered in the community, develop exercises on the comparative cost of farm buildings to farm lands. Problems in making out bills of lumber for pigpens, poultry houses, dairy barns, cribs, silos, etc., and finding cost of same may be made use of. As nearly as possible, use local material as a basis for exercises. Have the club girls furnish recipes of various dishes to be used as a basis for calculation on the cost of materials involved.

EXCURSIONS AND PRACTICAL WORK.

Weekly excursions should be made to near-by fields, or, better still, to the patches of club members (fig. 3) to study types of stalks and to make field selections of seeds. The stalks selected should be indicated by some kind of marking, so that they may be detected easily when seeds are matured and ready for gathering. Before going on these excursions publications pertaining to seed selection should be carefully read. It would be wise to take the publications for reference on these excursions.

Practical work in preparing equipment for storing seeds and arranging exhibit material for the school or county fair should be done in this month.

OCTOBER.

LANGUAGE LESSONS.

Reports of field observations. Compositions on modern methods of harvesting and modern methods of preparing leading crops for market. Descriptions of observations made at the school or county fair should be required. Letters to commercial people asking for prices and offering products for sale should be written. Make a record of practical work.

READING AND SPELLING.

The following are suggested for correlation reading: Farmers' Bulletins Nos. 113, Harvesting and Storing Corn; 258, Texas or Tick Fever and Its Prevention; 292,

FIG. 3.—School children visiting a club member's acre of corn, Elbert County Ga.

Cost of Filling Silos; 354, Onion Culture; 408, School Exercises in Plant Production; 436, Winter Oats for the South; 548, Storing and Marketing Sweet Potatoes; 617, School Lessons on Corn; and Bureau of Plant Industry Document No. 485, The Selection of Cotton and Corn Seed for Southern Farms.

List and assign the new words for spelling exercises.

DRAWING.

Prepare outline plans of poultry and hog houses, cribs, silos, and dairy barns. Make drawings of the less complicated harvesting machinery and the important parts of the same. In this connection emphasize the learning of the names and uses of implements and their parts.

HISTORY.

Study the history of crops of the community as to their origin, time, and circumstances of their introduction, and the success with which they have been grown. Also study the history of weeds, insects, and fungus diseases of the section as to origin, introduction, spread, damage done, and methods of combating.

GEOGRAPHY.

Study the topography of the State with reference to the effect that elevation has upon agricultural industry. Prepare outline maps to illustrate. Extend this study to other States and countries and note the effect of elevation, as compared with latitude, on crops, locating those sections that have similar products as a result of similar altitude or latitude.

ARITHMETIC.

Develop exercises on the capacity of bins, cribs, hay barns, silos, wagon beds, etc.; also on cost of harvesting crops, such as corn, cotton, cane, fruits, peanuts, potatoes, and on the cost of preparing salable crops for market. Let all exercises be based on local conditions and facts. These data should be collected by the club members of the school. During this month problems involving the annual reports of club members should be developed. The exercises should be so prepared as to involve as many of the principles of arithmetic as necessary.

EXCURSIONS AND PRACTICAL WORK.

Select seed from near-by fields and club plats from plants previously marked on the excursions. This is the month for fairs, and the pupils should visit these, observe exhibits, and collect facts for correlation exercises.

Practice in storing seed in previously prepared devices should be given. Let the economic importance of this work be emphasized. During this month pupils should get valuable training and practice in judging crops and animals. Let the school authorities insist on the officers of the fair association furnishing specialists for this purpose during fair week. The training and experience in scoring and judging of this week can be followed up by the teachers and pupils during the following months.

NOVEMBER.

LANGUAGE LESSONS.

Reports of field observations. Compositions on crop marketing, crop storing, and the feeding of crops. Written descriptions of bins, cribs, silos, and hay barns, modern in character, should be required. Make records of practical work. A description of the school's exhibit by the club members at the county or school fair with a record of the results obtained in the way of prizes, etc., should be made. Practice in letter writing should be had by applying to the Department of Agriculture for the necessary publications for the succeeding months' correlation exercises.

READING AND SPELLING.

The following are suggested for correlation reading: Farmers' Bulletins Nos. 298, Food Value of Corn and Corn Products; 379, Hog Cholera; 408, School Exercises in Plant Production; 438, Hog Houses; and 537, How to Grow an Acre of Corn.

List and assign the new words for spelling exercises.

DRAWING.

Prepare drawings of farm tools used in breaking and cultivating land, in fertilizing crops, and in general cultivation. When the implements are too complicated, make drawings of only the most essential parts. Keep in mind that the purpose is to teach the pupils the names and uses of implements and parts of implements.

HISTORY.

Study the history of the methods of preparation, cultivation, and harvesting of the various crops of your State and section that have obtained in the past and note the development. Compare these with methods employed in other sections and countries having similar products. Study the history of farm implements, noting the development, the saving of time and labor, and the increased efficiency.

GEOGRAPHY.

Study the time of planting crops, the maturing of crops, and the manner of housing crops and animals as affected by the elevation and latitude of your own State. Extend this study to a comparison of the same with other States and countries having similar agricultural productions.

ARITHMETIC.

Problems should be developed on the cost of liming land, turning land at different depths, on the economy in the use of improved machinery in turning land, on the crop yields for your county, State, and section, on facts gathered as to the farm products bought and sold by the State and country. Let problems be developed involving the value of farm products bought and sold by the home county and lessons deduced as to the status of your county in a financial way. Answer these questions: Do you produce more than you buy? Do you buy what you should produce? From records of pig-club members compare the relative value of scrub and pure-bred hogs. From records of poultry-club members develop problems on the production of the different breeds of poultry.

EXCURSIONS AND PRACTICAL WORK.

Excursions should be made to the farms of the community to study poultry, swine, horses, cattle, and sheep, for the purpose of practice in scoring (fig. 4) and to secure data for correlation exercises. On these visits to the farms implements should be observed to learn their names and uses. If there are any particular farmers who have new or specially improved implements for fall and winter plowing, visits should be made to observe these and to note their efficiency in use.

DECEMBER.

LANGUAGE LESSONS.

Reports of field observations. Prepare score cards for exercises of this kind in field crops. Compositions on value of improved farming implements, especially those that are adapted to your section, should be required. Compositions on the care of farm implements should also be required. Letters ordering farm-implement catalogues and bills of implements should be written. Copy records of practical work.

READING AND SPELLING.

Farmers' Bulletins Nos. 51 (Rev.), Standard Varieties of Chickens; 270, Modern Conveniences for the Farm; 321, The Use of the Split-Log Drag on Earth Roads; 408, School Exercises in Plant Production; 413, The Care of Milk and Its Use in the Home; and 541, Farm Buttermaking.

List and assign new agricultural terms for spelling exercises.

DRAWING.

Lay out school grounds and plat to a scale, showing the walks, flower yard, garden, clumps of shrubbery, trees, buildings, etc. Plat the school and home gardens to scale, showing walks and individual plats.

HISTORY.

Study the introduction and development of the use of fertilizer in the State and section, noting its effect on the agricultural development, the study that has been made to use it intelligently, the laws that have been passed relating to the fertilizer industry, and to what extent the use of fertilizers has proved beneficial.

FIG. 4.—A lesson on the beef type.

Study the organizations and functions of the State and national departments of agriculture and note in what particular way these departments have been helpful to your State.

GEOGRAPHY.

Study the trade that results from the exchange of agricultural products between your State and the other States and countries. Compare the exports and imports as to quantity, value, and character. Learn the means by which each home-produced article reaches the ultimate consumer. Extend this study to the trade relations of your section of the country with the other sections and with the other parts of the world. In this connection prepare maps showing lines of commerce and locate the principal receiving and distributing points for each agricultural product bought or sold.

ARITHMETIC.

Develop problems on the cost of keeping cows in the different homes of the community. Have pupils bring data as to the rations fed daily to the cows and from such determine the nutritive value and let it be shown whether the ration is balanced or not. Where the Babcock tester can be had let the milk of the various cows of the community be tested and from these facts develop problems showing the profitableness or unprofitableness of the individual cow, and by a comparison of the kind and cost of rations and returns from each cow let it be shown whether the profit or loss is due to the feeding or to the animal. Special problems in nutritive ratios should be developed for the benefit of the pig and poultry club members. This entire month can be spent in working out balanced food rations for the various farm animals of the community, combining foodstuffs in these rations that can be had

FIG. 5.—Fathers observing a corn-judging contest, New Martinsville, W. Va.

at the least cost. As a basis for these exercises the following publications are suggested for use: Farmers' Bulletins 22 (Rev.), Feeding Farm Animals; 346, The Computation of Rations for Farm Animals by Use of Energy Values; and 411, Feeding Hogs in the South.

EXCURSIONS AND PRACTICAL WORK.

Excursions for comparison of out-of-date and modern farm machinery, gins, and grain mills should be made. Trips should also be made for the purpose of practice in scoring farm animals.

Practical indoor work in scoring seeds should be engaged in during the months of December and January (fig. 5). Have specimens brought to the school by club members and the work carried on under the supervision of the teachers. When possible, have farmers bring animals to the school grounds for practice in scoring.

JANUARY.

LANGUAGE LESSONS.

Reports of field observations. Prepare systems of crop rotation adapted to your section. Write description of seed testers and methods of testing the vitality of seeds. Letters ordering material for seed testers and garden stakes or submitting bills of material should be written.

READING AND SPELLING.

The following are suggested for correlation work in reading this month: Farmers' Bulletins Nos. 185, Beautifying the Home Grounds; 213, Raspberries; 347, Repair of Farm Equipment; 375, Care of Food in the Home; 389, Bread and Bread Making; 408, School Exercises in Plant Production; 468, Forestry in Nature Study; 511, Farm Bookkeeping; and 538 and 539, On Citrus Growing in the Gulf States.

List and assign the new words and terms of an agricultural character appearing in the correlation exercises of the month.

DRAWING.

Have each pupil lay out his plat in the school garden and show in the diagram the location of each vegetable to be planted, indicating the rows or beds by name. Require drawings of all garden devices, such as stakes, tools, etc. During this month seed-testing boxes or cases should be planned and drawings made to a scale.

HISTORY.

Study the relationship of the agricultural products of the State and section to the political history of the State and country. Let this study begin with the settlement of the country and extend to the present. Emphasize the importance of the relationship by connecting particular crops with striking historical events and legislative enactment.

GEOGRAPHY.

Study and compare the forms of government, the prevailing customs, the religions, the classes of people and their personal characteristics in the different parts of your own State, in other States, and in other countries having agricultural industries similar to that of your own State and section.

ARITHMETIC.

At the beginning of the new year the older pupils, and especially the club members, should he encouraged to open books for the purpose of keeping accounts of the outlay and income of the farms of the community. Separate pages should be set apart for each farm crop and enterprise, providing both credit and debit columns. Each domestic animal should be assigned a page with credit and debit columns. If it is not an animal that labors or supplies some product for immediate consumption, and is not disposed of during the year, its credit column should show the increase in weight or value at the market price. Club members should open books and keep accurate records of their enterprises for the year.

Practice problems in determining the value of elements in fertilizers of given formulas, in the cost of compounding fertilizers of given formulas, and in determining the value of the time consumed in compounding fertilizers, should be developed. Data for the foregoing should be secured by visiting local warehouses or farms and examining the formulas found on the sacks of the various brands. Compare the cost of the home-mixed products with that of the commercial brands of the same formulas and note the saving, if any, by home mixing. Practice pupils in interpreting the formulas on fertilizer sacks.

EXCURSIONS AND PRACTICAL WORK.

The excursions for this month should be made for the purpose of securing data for the exercises mentioned in the other subjects.

The pupils of this group of classes should do practical work in compounding fertilizers for their contest plats, and to get as much practice as possible they should go in groups from one boy's home to another's to assist in compounding the fertilizers. The fertilizers to be used in the school garden should be compounded by the club members in the presence of the entire school and for its benefit.

All seed-testing devices should be prepared this month, and the seed to be tested assembled for the purpose.

FEBRUARY.

LANGUAGE LESSONS.

Compositions on the value of seed testing should be required. A most valuable exercise for the advanced pupils and club members would be to collect, classify, and record the agricultural statistics of the school district. Let this show what was produced the previous year, what kept on the farm, what sold, and what bought. This will not only give valuable practice in systematic work but will furnish the school and community with valuable information as to its agricultural status.

READING AND SPELLING.

The following are suggested for supplementary reading: Farmers' Bulletins Nos. 134, Tree Planting on School Grounds; 181, Pruning; 218, School Gardens; 236, Incubation and Incubators; 243, Fungicides and Their Use in Preventing Diseases of Fruits; 255, The Home Vegetable Garden; 389, Bread and Bread Making; 428, Testing Farm Seeds in the Home and in the Schools; 491, The Profitable Management of the Small Orchard on the General Farm; Bureau of Entomology Circular No. 54, Peach Tree Borer; and Bureau of Plant Industry Yearbook Reprint No. 197, How Birds Affect Orchards.

List and assign the new words as spelling lessons.

DRAWING.

Require pupils to bring to school specimens of all kinds of domestic plants affected by fungus diseases and make drawings of these, showing the appearance of the affected part. Require drawings of cuttings, proper and improper pruning (fig. 6), methods of grafting, pruning and grafting implements; also drawings of spraying devices. In connection with all these emphasize learning the names and the uses.

HISTORY.

Study the origin and development of the school-gardening movement, noting especially the purposes, the results that have been obtained, and its future possibilities in advancing the interests of the community, both as to vitalizing the school work and as a source of revenue for school enterprises.

GEOGRAPHY.

Study the relationship of the agricultural products of your county and State to the industrial development of the same. Compare your own State in this respect with other States and countries having similar agricultural products. If there is a difference in the industrial development in any of the cases noted let it be accounted for.

ARITHMETIC.

Problems on the value of selecting and testing seeds of the various crops should be developed for this month. Let the exercises involve the value of time spent in selecting and testing, the time spent in replanting, and the effect of untested seed on the stand and the ultimate yields. Let these exercises as nearly as possible be based on data gathered from the community. These processes may be multiplied to meet the needs of the different classes in the subject of arithmetic. Problems on the cost of spraying materials, the time spent in spraying, and the increased yield should be developed. Comparison should be made of the yields of sprayed and unsprayed trees, and problems developed on these as a basis. The value of sprays in prolonging the lives of plants should be estimated.

FIG. 6.—Practice in pruning.

Useful publications to be used in connection with this work are: Bureau of Entomology Circular No. 42, How to Control San José Scale; and Farmers' Bulletin 243, Fungicides and Their Use in Preventing Diseases of Fruits.

EXCURSIONS AND PRACTICAL WORK.

Excursions should be made this month to orchards for the purpose of observing methods in spraying and for practice in the use of spraying mixtures and devices. Excursions should also be made for the purpose of observing pruning and for practice in the same.

Practical work in testing seeds, both in the school and the home, should be engaged in. The actual work at school should be confined largely to school-garden seeds and those to be used by the club members in their contest plats.

MARCH.

LANGUAGE LESSONS.

Reports of field observations, compositions on the value of clubs to the members, the schools, and the community, and the influence of clubs on increased production and on home economy. Letters of correspondence between club members of different schools. Record of practical work. Debate: The Boll Weevil is a Blessing in Disguise.

READING AND SPELLING.

The following are suggested for supplementary correlation reading: Farmers' Bulletins 205, Pig Management; 229, Production of Good Seed Corn; 241, Butter Making on the Farm; 287, Poultry Management; 408, School Exercises in Plant Production; 417, Rice Culture; and 533, Good Seed Potatoes and How to Bed Them.

List and assign new words for spelling exercises.

DRAWING.

Have each pupil prepare a drawing of his home farm, locating buildings, yards, barn lots, permanent pasture, orchards, streams, springs, woodland, roadways around or through the farm, crops as planned for the year, the prize acres and plats, etc. After an accurate outline has been drawn the map can be made attractive by filling in with seed, fiber, pictures of fruit, stock, farm implements, flowers, and houses at proper places on the map. On farms where a system of rotation is followed a set of maps should be drawn representing the location of the crops for each year of the course.

HISTORY.

Study the history of the agricultural-club movement in your State and in other States. Collect and study data as to records of prize winners, methods employed by them, and value of prizes and advertising received by the winners. Study the systems of judging yields employed in your State and other States.

GEOGRAPHY.

Prepare a map of the United States and indicate the States in which there has been club activity, the kinds of clubs, and prepare a statement in this connection showing the influence of the club movement on the school and farm work of each State. Also study the influence of clubs on increased production, crop marketing, home life, and health.

ARITHMETIC.

Develop problems on the cost of farm fencing. Special attention should be given to the cost of constructing temporary hog and poultry fences. Exercises in this phase of the work should be developed for the benefit of the club members. Problems relating to the cost and value of grazing crops for hogs and poultry should be developed.

EXCURSIONS AND PRACTICAL WORK.

The time that can be devoted to excursions should be spent in visiting the different club members' patches for the purpose of observing the methods and thoroughness of preparation.

Practical work for this month should consist in preparing plats and patches for planting the contest crops.

APRIL.

LANGUAGE LESSONS.

Reports of field observations. Compositions on methods of growing given crops, such as corn, potatoes, and tomatoes. The following points should be covered in each composition: Preparation of soil, fertilization, cultivation, and harvesting. Write letters to the State extension agent asking advice and information as to matters pertaining to your club work. Make a record of practical work. Debate: "The corn-club movement" has done more to increase the yield of corn in the State during the last five years than any other one influence.

READING AND SPELLING.

For correlation reading the following are suggested: Farmers' Bulletins Nos. 54, Some Common Birds; 220, Tomatoes; 372, Soy Beans; 414, Corn Cultivation; 431, The Peanut; 458, The Best Two Sweet Sorghums for Forage; 459, House Fly; and 509, Forage Crops for the Cotton Regions.

The usual method of listing and assigning words should be employed.

DRAWING.

During the months of April and May the pupils of this group should spend the time to be devoted to drawing in gathering data and preparing a map of the school township or district, showing the location of all public enterprises that touch upon farm life. These will include the following: Principal and neighborhood roads, telephone line, rural carriers' routes, church buildings, school buildings, railroads, railway stations, sidetracks, community markets, if any, streams, mills, gins, etc. This map should be so complete that it will show all the advantages and disadvantages of the township or school district. Complete this map by locating the homes of the boys and girls who belong to the clubs and have contest plats.

HISTORY.

During the months of April and May, or the closing month of the school, special attention should be given to the study of the histories of crops or breeds of animals to be grown by the club members, laying special emphasis on the degree of success with which each has been produced and the conditions that have obtained in connection therewith. It will be especially important to study the methods of preparing seed beds, of fertilizing, of planting, and of cultivating that have been employed in the past, to determine with what success these methods have been employed and to what extent they should be used by the club members. This study should be extended to methods of feeding poultry and swine, noting especially the success of the different methods and the conditions that obtained in each case.

GEOGRAPHY.

Prepare a map of the State, indicating thereon by distinguishing marks the different classes of schools teaching agricultural sciences. Continue this study to the Nation and to other countries and determine as nearly as possible the effect that such institutions have had on agricultural advancement and how agricultural conditions have affected the work of the schools.

ARITHMETIC.

Develop problems on crop rotation, estimating the value of the same in soil improvement and in saving in the cost of fertilizers. Plan rotations especially adapted to the needs of the corn and pig club members, based on proper rotation principles, and at the same time providing feed and grazing for hogs. Develop exercises based on the foregoing for work in the arithmetic classes.

EXCURSIONS AND PRACTICAL WORK.

Visits should be made to places in the community affording opportunities for the studying of hotbeds, cold frames, and their structure and use.

The months of April and May should be devoted to planting contest crops and germinating plants for the purpose of transplanting later.

MAY.

LANGUAGE LESSONS.

The closing days of school are generally used preparing exercises for the final public entertainments. These exercises should be full of the subject of agriculture. Let all the selections rendered touch upon some phase of agriculture. This will be an opportunity for the teacher to show in a public way what the school can do for the community in connection with its most important enterprise.

READING AND SPELLING.

The following are suggested for correlation reading: Farmers' Bulletins Nos. 132, Insect Enemies of Growing Wheat; 426, Canning Peaches on the Farm; 447, Bees; and 521, Canning Tomatoes in the Home and in Club Work.

The same plan with regard to the spelling exercises should be followed as in other months.

DRAWING AND HISTORY.

Same as in April.

GEOGRAPHY.

Study birds of the State with regard to habits of migration. Compare those that migrate and those that do not as to their agricultural economy. Study insects and fungus diseases of the State as to kinds, localities infested, and the influence they have on the kinds and yields of crops.

ARITHMETIC.

Develop problems on cost of terracing, estimated saving of terraces, cost of open ditches, cost of blind ditches, and problems involving the relative values of blind and open ditches with reference to original cost, saving in cultivatable ground, time in cultivation, keeping open ditch clear of weeds, etc. Multiply problems on the economy of birds in destroying weed seeds, insects, and insect eggs. (See Yearbook Reprint No. 443, Does it Pay Farmers to Protect Birds? Also Farmers' Bulletin No. 187, Drainage of Farm Land.)

CORRELATION SUPPLEMENTS.

REFERENCES.

Let each school provide itself with the publications of the Department of Agriculture mentioned in this scheme and arrange them according to subjects in a permanent place in the school building. These publications may be had as long as the supply lasts by applying to the Department of Agriculture, Washington, D. C.

Each school should write to the State college of agriculture asking that its name be listed to receive such matter printed by the college and the experiment station connected with it as is of value in the school work.

Have the pupils bring from home the farm papers that have been read there.

Group your publications after some convenient plan and form the habit of using them in connection with your work.

Almost unlimited reference material may be had free. Use a few postal cards and command this material. Create an agricultural atmosphere in the school, thereby making it a real center of activity in the community.

Agricultural colleges in the Southern States:

- Alabama Polytechnic Institute, Auburn, Ala.
- College of Agriculture of the University of Arkansas, Fayetteville, Ark.
- College of Agriculture of the University of Florida, Gainesville, Fla.
- Georgia State College of Agriculture, Athens, Ga.
- State University and College of Agriculture, Lexington, Ky.
- Louisiana State University and Agricultural and Mechanical College, Baton Rouge, La.
- Maryland Agricultural College, College Park, Md.
- Mississippi Agricultural and Mechanical College, Agricultural College, Miss.
- The North Carolina College of Agriculture and Mechanic Arts, West Raleigh, N. C.
- Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
- The Clemson Agricultural College of South Carolina, Clemson College, S. C.
- College of Agriculture, University of Tennessee, Knoxville, Tenn.
- Agricultural and Mechanical College of Texas, College Station, Tex.
- Virginia Polytechnic Institute, Blacksburg, Va.
- West Virginia University and Agricultural and Mechanical College, Morgantown, W. Va.

SEED SELECTING.

As soon as possible after the opening of school in the fall trips to to club patches and near-by fields should be made and typical plants located, from which seeds are to be selected later. Plants should be selected that have made the best showing as to symmetrical growth and number and quality of seed under average conditions. For instance, do not be misled by an attractive, symmetrical, highly productive specimen that happens to have unusual distance or stands on an unusually fertile spot. Select the plant that has outstripped its neighbors in the before-mentioned characteristics under average conditions.

Let these individuals be marked in some way so that they may be located readily when seeds have matured.

Later in the season, after the seeds have matured and in advance of general harvesting, go back to the fields or plats and select the choice specimens of seed from stalks previously marked.

Such seed should be stored in a dry, cool place to await germinating and vitality tests.[1]

[1] See U. S. Dept. Agr., Bu. Plant Indus. Doc. 485, The Selection of Cotton and Corn Seed for Southern Farms.

SEED STORING.

Care should be exercised in storing seed that its vitality may be preserved. Extremes in temperature, excessive moisture, and attacks of rodents, insects, etc., should be provided against. If the farm buildings are not equipped with a room especially prepared for storing seed, racks should be used, which may be suspended from points inaccessible to small animals. To prevent insect injury, grains especially should be fumigated with bisulphid of carbon. Seeds that are likely to be affected with fungus diseases should be treated with a formalin solution before planting.[1]

SEED TESTING.

The work in testing garden and field-crop seeds should prove one of the most interesting, as well as one of the most valuable exercises

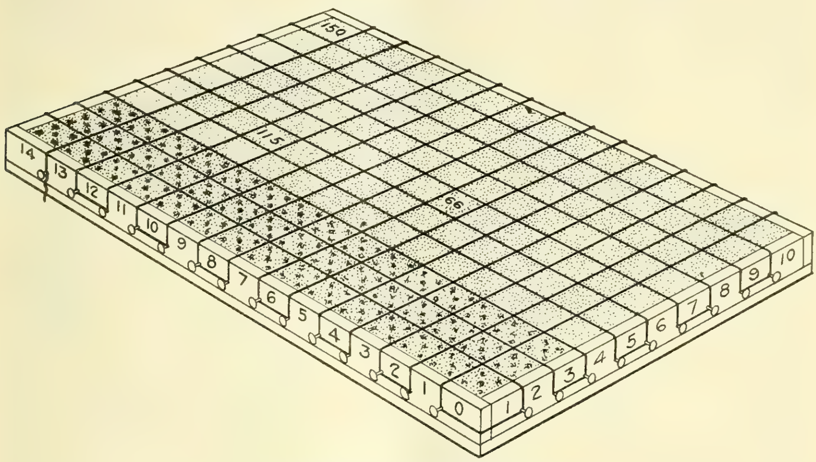

FIG. 7.—Sand tray for testing seed corn.

that the club members and the schools can engage in. No special skill is required.

The accompanying seed-testing device (fig. 7) will suggest the principal equipment.[2]

The value of seed testing in securing regular stands of healthy, vigorous plants can not be overestimated.

PLANS FOR SCHOOL GARDENS.

The plan for the school garden will depend upon a number of things, among them being the land available, the number of pupils, and the size of the individual plats. In the event that the school

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[1] See U. S. Dept. Agr. Farmers' Buls. 243 and 544.

[2] Special attention is called to U. S. Dept. Agr. Farmers' Bul. 428, Testing Seed in the Home and in the School.

grounds do not supply a sufficient amount of land arrangements should be made to secure a plat adjacent to the school.

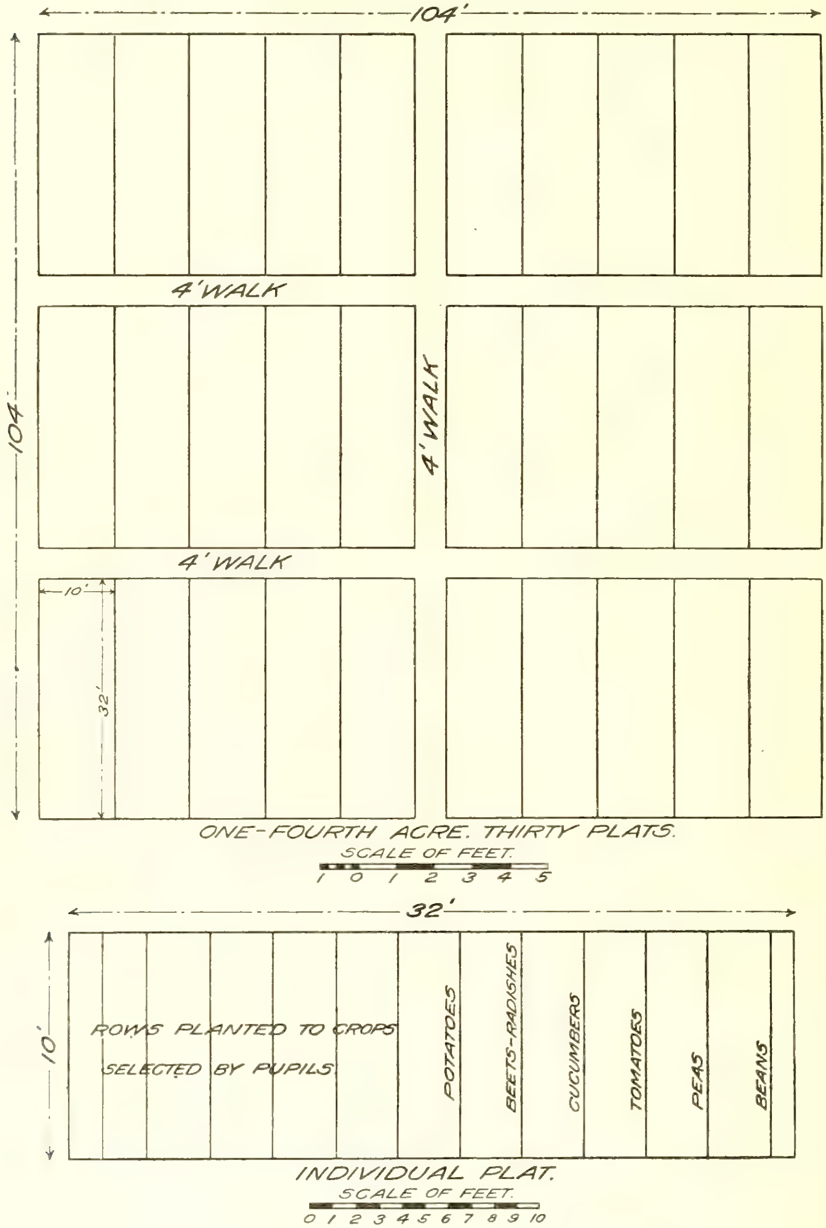

FIG. 8.—Suggestive plan for a school garden and an individual plat.

The mistake of making the individual plats too large should not be made. Just sufficient area should be assigned to enable the pupil to give it proper attention. Careful, thoughtful work should be insisted upon rather than quantity.

Demonstration plats for the supervision of the teacher should be set apart. These plats should be used to demonstrate certain truths with regard to individual crops. The farmers of the community should be encouraged to take an interest in this phase of the work for their own benefit.

The preceding school-garden plan (fig. 8) should prove suggestive to the teacher in laying out grounds.

SCHOOL EXHIBITS.

Every school should have its fair or its exhibit day. There are many reasons for this. In the first place, such an enterprise is local

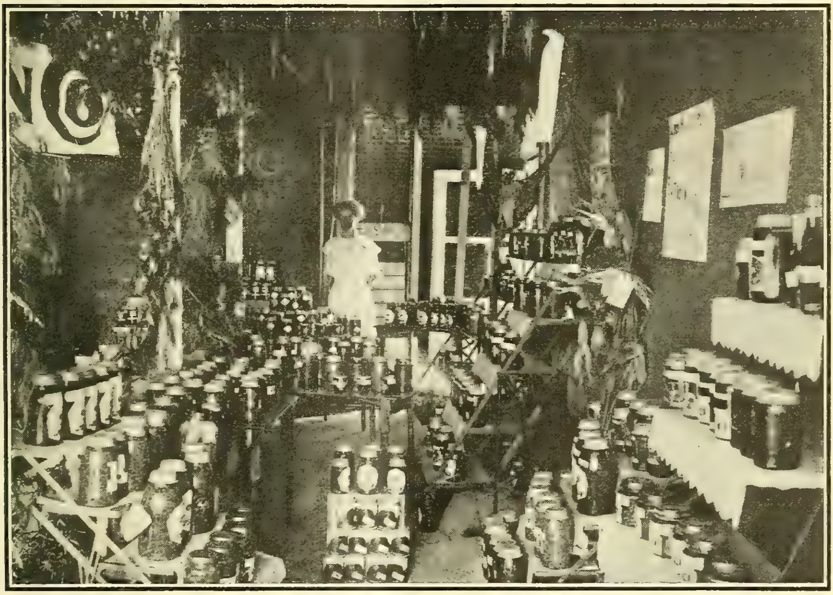

FIG. 9.—Marion County, Tex., Girls' Club exhibit.

in character, and it is possible for every pupil to participate. Looking forward to an exhibit of products and work will prove quite an incentive to the pupil to do his or her best in the garden, plat, or other work. The interest thus awakened among pupils will react on the community and attract its attention to the school. It will be necessary to offer prizes for the best exhibits, and in soliciting the articles for this purpose the attention of beneficent and enterprising people will be called to the progressive spirit of the school and its importance magnified. In turn, the recognition given the school by patrons and others will prove encouraging to the pupils and will be conducive to better results in their work.

Aside from the benefits of an inspirational character the pupils will be rewarded with better yields and in some instances with prizes of intrinsic value.

As a means of raising funds for school improvement the prize-winning exhibits should be sold at auction.

The exhibits (fig. 9), excepting live stock, can be displayed either within or without the school building. Seats and simple contrivances may be employed for the display. Nothing appears to better advantage than agricultural or home-economic products. The exercise of a little taste in the arrangement will produce surprising results.

Finally, the school fair will provide a means of collecting and preparing material for the district or county fair, if such is conducted.

SCORE CARDS.

SCORE CARD FOR LARD HOGS.

Breed.................. Name........................ Register No. ....

	Perfect score.	Student's score.	Corrected score.
General appearance, 36:			
Weight, score according to age	6		
Form, deep, broad, low, long, symmetrical, compact, standing squarely on legs	10		
Quality, hair silky; skin fine; bone fine; flesh smooth, mellow, and free from lumps or wrinkles	10		
Condition, deep, even covering of flesh, especially in regions of valuable cuts	10		
Head and neck, 6:			
Snout, medium length, not coarse	1		
Eyes, full, mild, bright	1		
Face, short, cheeks full	1		
Ears, fine, medium size, soft	1		
Jowl, strong, neat, broad	1		
Neck, thick, medium length	1		
Fore quarters, 10:			
Shoulders, broad, deep, full, compact on top	6		
Breast, advanced, wide	2		
Legs, straight, short, strong; bone clean; pasterns upright; feet medium size	2		
Body, 30:			
Chest, deep, broad, large girth	2		
Sides, deep, lengthy, full; ribs close and well sprung	6		
Back, broad, straight, thickly and evenly fleshed	10		
Loin, wide, thick, straight	10		
Belly, straight, even	2		
Hind quarters, 18:			
Hips, wide apart, smooth	2		
Rump, long, wide, evenly fleshed, straight	2		
Ham, heavily fleshed, plump, full, deep, wide	10		
Thighs, fleshed close to hocks	2		
Legs, straight, short, strong; bone clean; pasterns upright; feet medium size	2		
Total	100		

Remarks...

Name of pupil.................................. Date.......................

SCORE CARD FOR BACON HOGS.

Breed .... Name .... Register No. ....

	Perfect score.	Student's score.	Corrected score.
General appearance, 36:			
Weight, 170 to 200 pounds; largely the result of thick covering of firm flesh	6		
Form, long, level, smooth, deep	10		
Quality, hair fine, skin thin; bone fine; firm, even covering of flesh without any soft bunches of fat or wrinkles	10		
Condition, deep, uniform covering of flesh, especially in regions of valuable cuts	10		
Head and neck, 6:			
Snout, fine	1		
Eyes, full, mild, bright	1		
Face, slim	1		
Ears, thin, medium size	1		
Jowl, light, trim	1		
Neck, medium length, light	1		
Fore quarters, 10:			
Shoulders, free from roughness, smooth, compact, and same width as back and hind quarters	6		
Breast, moderately wide, full	2		
Legs, straight, short, strong; bone clean; pasterns upright, short; feet medium size	2		
Body, 34:			
Chest, deep, full girth	4		
Back, medium and uniform in width, smooth, slightly arched	8		
Sides, long, smooth, level from beginning of shoulders to end of hind quarters. The side at all points should touch a straight edge running from fore to hind quarter	10		
Ribs, deep	2		
Belly, trim, firm, thick without any flabbiness or shrinkage at flank	10		
Hind quarters, 14:			
Hips, smooth, wide; proportionate to rest of body	2		
Rump, long, even, straight, rounded toward tail	2		
Gammon, firm, rounded, tapering, fleshed deep, and low toward hocks	8		
Legs, straight, short, strong, feet medium size; bone clean; pasterns upright	2		
Total	100		

Remarks ....

Name of pupil .... Date ....

SCORE CARD FOR COTTON PLANT.

Class.................................. Variety..................................

The cotton plant.	Perfect score.	Student's score.	Corrected score.
Plant, vigorous, stocky, 25 points:			
Size	5		
Form, symmetrical, spreading, conical	5		
Stalk, minimum amount of wood in proportion to fruit	5		
Branches, springing from base, strong, vigorous, in pairs, short jointed, inclined upward	5		
Head, well branched and filled, fruited uniformly	5		
Fruiting, 24 points:			
Bolls, large, uniformly developed, plump, sound, firm	4		
Number of bolls, according to variety	4		
Bolls per pound of seed cotton, large, 40–60; medium, 60–75; small, 80–110	4		
Character of bolls, number of locks 4 to 7; kinds of sepals; retention of cotton	6		
Opening of bolls, uniform including top crop, classify as good, medium, poor	6		
Yield—Standard 1 bale per acre, 30 points:			
Seed cotton, estimated by average plant, distance of planting, per cent of stand, plants per acre; thin uplands, 10,000; fertile uplands, 6,500; "bottoms," 4,500; distance of plants, $3\frac{1}{2}$ by $1\frac{1}{4}$ feet, $4\frac{1}{2}$ by $1\frac{1}{2}$ feet, $4\frac{1}{2}$ by 2 feet, respectively	12		
Per cent of lint, not less than 30, standard 40	12		
Seeds, 30–50 per boll, large, plump, easily delinted; color, according to variety; germination not less than 95 per cent	6		
Quality and character of lint, 21 points:			
Strength, tensile strain good, even throughout length	5		
Length, long, according to local standard; upland, $\frac{7}{8}$ to 1 inch; intermediate, $1\frac{1}{4}$ to $1\frac{3}{8}$ inches; long staple, $1\frac{1}{2}$ to 2 inches	5		
Fineness, fibers soft, silky and pliable, responsive to touch	5		
Uniformity, all fibers of equal length, strength, fineness	5		
Purity, color dead white; fiber free from stain, dirt, and trash	1		
Total	100		

Remarks..

Name of pupil.................................. Date........................

SCORE CARD FOR CORN.

Class.................................. Variety..................................

STANDARD.

Stalks per acre.......................... Ears per stalk..........................

Weight of ears....................pounds. Yield per acre....................bushels.

Length......................inches. Grain..................................

Ear: Color:

Circumference....................inches. Cob..................................

	Standard.	Student's score.	Corrected score.
Uniformity:			
a. Uniformity of exhibit b. Trueness to type	10		
Shape of ear, cylindrical	10		
Weight, according to standard	10		
Length, according to standard	5		
Circumference, according to standard	5		
Market condition and quality, sound and bright	20		
Color, no discolored grains	5		
Tips, covered over end	10		
Butts, filled out, rows straight	5		
Space between rows, very little	5		
Uniformity and shape of kernels	10		
Per cent of grain, estimated..........Found........	5		
Total	100		

Remarks..

Name of pupil.................................. Date........................

SCORE CARD FOR POTATOES.

Variety.................................. Spring or fall crop..................

		Perfect score.	Student's score.	Corrected score.
Size (not overlarge nor undersized)		20	....	....
Shape (true to type of variety, whether round, cylindrical, or kidney shaped)		10	....	....
Color		10	....	....
Skin	5			
Flesh	5			
Surface (should be smooth)		20	....	....
Eyes		20	....	....
Number (not less than 8 nor more than 12)	5			
Distribution (not too close together, some eyes on each quarter)	5			
Depth (not too deeply indented nor raised above surface)	10			
Freedom from blemish (scab, rot, or insect injury)		20	....	....
Total		100	....	....

Remarks...
Name of pupil.................................. Date..........................

SCORE CARD FOR BUTTER.

Breed of animal................ Name................ Registration No......

	Perfect score.	Student's score.	Corrected score.	
Flavor	45	....	....	Metallic. Curdy. Fishy. Feverish. Oily. Weedy. Stable. Unclean. High acid. Low acid.
Texture	25	....	....	Poor grain. Weak body. Cloudy brine. Too much brine. Cheesy. Greasy. Tallowy.
Color	15	....	....	Mottles. White specks. Too high. Too light. Streaky.
Salt	10	....	....	Too much salt. Poor salt. Lacks salt. Gritty.
Condition of package	5	....	....	Dirty. Poorly packed. Poorly nailed. Poorly lined.
Total	100	....	....	

Remarks...
Name of pupil.................................. Date..........................

SCORE CARD FOR JELLIES.

Kind of fruit..

	Perfect score.	Student's score.	Corrected score.
Quality:			
Consistency—			
Solidification	25		
Firmness	15		
Taste—			
Tartness	10		
Flavor	10		
Appearance:			
Clearness	25		
Color	10		
Package—			
Production	3		
Condition	2		
Total	100		

Remarks..
Name of pupil.............................. Date......................

SCORE CARD FOR FRUIT AND VEGETABLES.

Kind of fruit or vegetable...................... Variety......................

	Perfect score.	Student's score.	Corrected score.
Taste:			
Tartness	15		
Flavor	15		
Appearance:			
Uniformity—			
Shape	15		
Size	15		
Color	20		
Arrangement	15		
Package:			
Production	3		
Condition	2		
Total	100		

Remarks..
Name of pupil.............................. Date......................

SCORE CARD FOR BREAD.

Kind..

	Perfect score.	Student's score.	Corrected score.
Outside:			
Color—			
Shade	4		
Evenness	3		
Surface	6		
Shape	7		
Inside:			
Thoroughness of baking	20		
Appearance of crumb—			
Texture—			
Quality	8		
Fineness	4		
Evenness	3		
Color	5		
Taste—			
Sweetness	25		
Flavor	15		
Total	100		

Remarks..

Name of pupil.................................. Date..........................

SCORE CARD FOR TOMATO PLANT.

Variety..

	Perfect score.	Student's score.	Corrected score.
Form	10		
Vigor	25		
Foliage	10		
Product (quantity and quality)	35		
Disease (plant and product)	20		
Total	100		

Remarks..

Name of pupil.................................. Date..........................

SCORE CARD FOR TOMATOES—PLATE.

Variety..

	Perfect score.	Student's score.	Corrected score.
Shape (should be ideal for variety)	15		
Blow or blossom end (small scar or smooth)	10		
Stem end (small, slight depression)	10		
Color (uniform and ideal for variety)	15		
Flesh (solidity)	10		
Flesh (uniform color)	10		
Even ripening for individual fruits	15		
Uniformity of sample	15		
Total	100		

Remarks..

Name of pupil.................................. Date..........................

SCORE CARD FOR APPLES—BARREL PACK.

Variety..

	Perfect score.	Student's score.	Corrected score.
Uniformity of size	20		
Uniformity of color	20		
Uniformity of shape	10		
Condition and freedom from blemishes	20		
Attractiveness, including facing and tailing	15		
Barrel, and trimmings	5		
Firmness of pack	10		
Total	100		

Remarks..
Name of pupil.............................. Date..............................

SCORE CARD FOR APPLES—PLATE.

Variety..

	Perfect score.	Student's score.	Corrected score.
Size (Normal: Neither too large nor too small)	10		
Color, typical	25		
Freedom from blemish	20		
Texture and flavor	20		
Uniformity and trueness to type	25		
Total	100		

Remarks..
Name of pupil.............................. Date..............................

SUGGESTED PROBLEMS IN ARITHMETIC.

SEPTEMBER.

1. Provide the school with several rod ($16\frac{1}{2}$-foot) poles marked off in foot and yard lengths. These should be made by the pupils.
2. With a pole, measure the school yard and find the area.
3. With a pole, measure club members' plats and find the areas.
4. With a pole, measure two areas a rod square in each boy's plat, count the stalks in each area, find the average number in each, and estimate the number of stalks in each boy's plat.
5. Count the ears, bolls, etc., on each area, find the average number on each area, and estimate the number on the entire plat. Estimate the yield and the value of the yield.
6. Prepare a bill of lumber for a hog house 6 by 36 feet, allowing for five partitions. The outside walls are 4 feet high and the summit of the roof 6 feet high. Find the cost of material at local prices.

OCTOBER.

1. A bushel measure for gauging corn is 12 by 12 by 27 inches. Find its volume in cubic inches. In cubic feet.
2. How many bushels of corn in a wagon box 10 feet long, 3 feet wide, and $2\frac{1}{4}$ feet deep?

3. How many cubic feet in a bin of sufficient capacity to contain the yield of a boy's acre that makes 156 bushels?

4. Find the profit made on a tenth of an acre of tomatoes when the land rent is $1, labor $3, staking and pruning $2, fertilizer $2.50, cans $36, canner $5, cost of canning $10, and the output 1,200 cans, at 8 cents per can.

5. Find the per cent profit in problem 4.

NOVEMBER.

1. What will it cost per acre to set an apple orchard if young trees cost 25 cents apiece and are planted in squares 36 feet apart?

2. If it requires 15 bushels of corn, at 50 cents a bushel, and $5 worth of other feed to raise a pig to be 9 months old, what is the cost of the pig to the boy?

3. If a scrub pig nets 150 pounds and is sold at 8 cents per pound when 9 months old, will there be a net profit or loss?

4. If a pure-bred pig nets 250 pounds when 9 months old and is sold at 8 cents per pound, is there a profit or loss?

5. A poultry club girl has a flock of 15 hens. Each hen averages 96 eggs per year. What is the value of all the eggs at 15 cents per dozen?

6. She feeds her flock of hens during the year 3 bushels of corn at 50 cents a bushel, 1 bushel of oats at 50 cents a bushel, and $2 worth of other feed. What is her profit?

7. The second year she improves her stock, and each hen averages 120 eggs. What is her profit?

DECEMBER.

1. A farmer owns 12 cows that average 22 pounds of milk each daily. How many pounds does his herd produce in a year?

2. If the milk of the above herd tests 4 per cent butter fat, what is the value of the year's production at 25 cents per pound butter fat?

3. If by changing the nutritive ratio of the feed the above-mentioned farmer increases the production of each cow 2 pounds per day without additional cost, what will be his increased receipts? What will be the per cent increase?

4. Each cow of a Holstein herd averages 30 pounds of milk daily, each cow of a Jersey herd 20 pounds, and each cow of a scrub herd 15 pounds. The Holstein milk tests $3\frac{1}{2}$ per cent butter fat, the Jersey 5 per cent, and the scrub $3\frac{1}{4}$ per cent. Find the value of the average daily production of butter fat of each cow at 25 cents per pound.

JANUARY.

1. A fertilizer formula sets forth the available essential elements—namely, phosphoric acid, ammonia, and potash—that the particular brand contains. For example, a 10:2:2 formula means 10 per cent phosphoric acid, 2 per cent ammonia, and 2 per cent potash. Find the number of pounds of each element in a ton (2,000 pounds) of 10:2:2 goods.

2. If phosphoric acid is worth 4 cents per pound, ammonia 15 cents per pound, and potash 5 cents per pound, find the cost of the fertilizing elements in a 10:2:2 goods.

3. If a ton of 10:2:3 goods cost $24 in market, what would be the value of a man's time (5 hours) who compounds his own fertilizer by the same formula when the elements cost the same as in problem 2?

4. Acid phosphate usually found on the market contains 14 and 16 per cent phosphoric acid; kainit usually contains 12 per cent potash; muriate of potash contains 50 per cent potash; nitrate of soda contains 16 per cent nitrogen, or approximately $19\frac{1}{2}$ per cent ammonia; cottonseed meal usually contains 2 per cent phosphoric acid, 7 per cent ammonia, and $1\frac{1}{2}$ per cent potash.

5. Find the value of the elements in a ton of cottonseed meal at the prices mentioned in problem 2.

6. Find the amounts of 16 per cent phosphate, 19½ per cent nitrate of soda, and 12 per cent kainit required to compound a ton of 9:2:4 goods. What amount of filler will be required to complete the ton?

7. Find the amounts of 14 per cent phosphate, 2:7:1½ cottonseed meal, and 50 per cent muriate of potash required to make a ton of 8:3:3 goods.

FEBRUARY.

1. Spraying materials usually cost as follows: Lime, 1 cent per pound; copper sulphate, 10 cents per pound; Paris green, 30 cents per pound; arsenate of lead, 15 cents per pound; kerosene, 13 cents a gallon; hard soap, 10 cents per pound; lime-sulphur mixture, 15 cents per gallon.

2. Find the cost of the following formula:

5 pounds lime	
5 pounds copper sulphate	
50 gallons water	
Total	

3. Find the cost of the following formula:

2 gallons kerosene	
1 pound hard soap	
1 gallon water	
Total	

4. Find the cost of the following formula:

3 pounds arsenate of lead	
50 gallons water	
Total	

5. If it takes three applications of 2 pounds of arsenate of lead and three days' time, at $1.25 per day, to destroy the Colorado beetles on an acre of potatoes, how many bushels of potatoes, at 50 cents per bushel, will be required to pay for the treatments?

6. A boy failed to select and test the vitality of his seed corn and secured only three-fourths of a regular stand. His yield was 60 bushels. What should it have been if his stand had been regular?

7. If two days had been required to select and test the corn seed in problem 6 and thereby secure a regular stand, what would have been the value of the boy's time per day?

MARCH.

1. For the school garden plats 15 girls want 10 tomato plants each, and the plants should stand 1½ inches each way, what should be the area of the cold frame?

2. Determine the cost of such a frame.

3. What would be each girl's share of the cost?

4. A boy who is a member of both corn and pig clubs follows a 3-year rotation course with 3 acres of land. To utilize his grazing crop each year it is necessary for him to have a portable hog fence of sufficient length to inclose an acre. If it requires 60 rods of fence at 35 cents per rod and 80 posts at 10 cents apiece to construct the fence, what will be the cost of material?

5. If the above boy's temporary pea pasture will support a sow and six pigs, what will each of the pigs have to bring at 10 weeks old to pay for his temporary fence?

APRIL.

1. In a 3-year rotation course of corn, cotton, and oats and peas, one-fourth ton of stubble and one-fourth ton of pea vines are turned under. What is the fertilizing value if 1 ton of pea vine provides 40 pounds nitrogen, 10 pounds phosphoric acid,

and 40 pounds potash; and 1 ton of stubble provides 10 pounds nitrogen, 4 pounds phosphoric acid, and 20 pounds potash?

2. A farmer plants an acre to cotton three years in succession, using 400 pounds of fertilizer each year. The first year the acre produces a bale, the second year five-sixths of a bale, and the third year two-thirds of a bale. What is the income for the three years if cotton sells at 12 cents a pound and seed at $20 a ton? (A bale of lint weighs 500 pounds. The seed of a bale 800 pounds.)

3. The same farmer plants another acre, using the same amount of fertilizer each year, to cotton the first year and makes a bale, to corn and peas the second year and produces 75 bushels of corn and 10 bushels of peas, to oats and peas the third year and produces 40 bushels of oats and 15 bushels of peas. Find the value of all the crops if corn is worth 75 cents per bushel, cotton the same as in problem 2, peas $1.50 a bushel, and oats 50 cents per bushel.

4. Find the fertilizer value of one-fourth ton of oat stubble and one-half ton pea vines turned under during the three years in problem 3.

5. Find the total values in problems 3 and 4 and compare with 2.

6. Will the method followed in problem 2 or that in problem 3 furnish more humus? Which method will leave the soil in better physical condition?

MAY.

1. Field tiling costs about as follows: Three-inch, 3 cents per foot; 4-inch, 4 cents per foot; 5-inch, 5 cents per foot; and 6-inch, 6 cents per foot. Find cost of 500 feet of each?

2. A man owns a plat of swamp land 48 rods long and 10 rods wide. Find its area in acres.

3. There is a small stream running through the middle of the plat lengthwise. To drain the plat into the stream it requires 4-inch tiling laid 2 feet deep every 4 rods. Find cost of tiling to drain the plat.

4. It costs 12½ cents a rod to dig the ditches. What will the ditching cost?

5. What will the system of drainage cost in 3 and 4?

6. The plat has been producing 2 tons of hay valued at $10 per ton. How many bushels of corn per acre will the plat now have to produce the first year to pay for the drainage system and make a return equivalent to the usual income from the hay crop?

7. Fifty insects per day is a low estimate for the average bird to eat. On an 80-acre farm there is an average of 2 birds per acre. How many insects will be consumed on this farm per day? Per month?

8. If there averages 1 bird per acre, how many in your State?

9. If each bird eats one-tenth of an ounce of weed seed per day, how many pounds of weed seed would be consumed in the State in a day? In August, September, and October?

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U.S. DEPARTMENT OF AGRICULTURE

No. 133

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
September 16, 1914.

EXPERIMENTS WITH CROPS UNDER FALL IRRIGATION AT THE SCOTTSBLUFF RECLAMATION PROJECT EXPERIMENT FARM.[1]

By Fritz Knorr,

Farm Superintendent, Office of Western Irrigation Agriculture.

INTRODUCTION.

In western Nebraska, as in many other portions of the Great Plains area, precipitation during the fall and winter months is comparatively light. In these sections the major portion of the rainfall of the year occurs from April to October. As a rule, the precipitation occurring between October and April comes as light showers or as light snowfalls. As a result of this condition, it is very commonly found that land which has produced a crop the preceding year contains very little moisture at planting time in the spring. On irrigated lands this condition is frequently unfavorable to field crops. When at planting time the soil contains insufficient moisture to germinate the seed and to support the early growth of the crop, it is necessary to irrigate early in the spring. Early spring irrigation may be objectionable for three reasons: (1) It is frequently difficult to secure irrigation water as early as it is needed; (2) when it is necessary to irrigate the land but a short time before crops are planted, it is difficult, and sometimes impossible, to secure satisfactory moisture conditions in the lower depths of soil, not only in the spring but during the greater part of the season; and (3) early spring irrigation may so saturate the surface layers of soil as to delay seriously the planting of the crop.

[1] The Scottsbluff Experiment Farm is located on the North Platte Reclamation Project, 6 miles east of Mitchell and about 8 miles northwest of Scottsbluff, Nebr. The tract consists of 160 acres of land irrigated from the Government canal. Though the entire tract is irrigable, about 30 acres are devoted to dry-land experiments. The land was withdrawn from entry by the Department of the Interior for use as an experiment farm, and operations were begun in 1909. Three of the original buildings were erected by that department. The farm is under a superintendent detailed by the Office of Western Irrigation Agriculture. The work is supported by Federal appropriation through the United States Department of Agriculture and by State appropriation through the University of Nebraska. The buildings on the farm outside of the original three structures have been erected from State funds.

Note.—The results of a 3-year experiment reported in this bulletin indicate that fall irrigation in the irrigated sections of the Great Plains area produces an increase in yield of field crops more than compensating for the cost.

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Several years ago it was suggested that the soil-moisture conditions in sections where the winter precipitation was light might be very much improved if the soil was saturated with irrigation water after the crop was removed in the fall. It seemed likely that an application of water at this time would afford an opportunity for establishing satisfactory moisture conditions, not only in the surface soil but in the subsoil to a depth of 6 feet or more during the time elapsing between fall irrigation and the planting of crops the following spring. It was thought that if this were true better crops might be produced in certain irrigated sections of the Great Plains area if fall irrigation were practiced. In order to determine what effect fall irrigation would have on the crops grown, a series of experiments was started at the Scottsbluff Experiment Farm in the fall of 1910. These experiments were continued in 1911, 1912, and 1913, and three years' results are now available for consideration. An account of these experiments and the results secured is given in this bulletin.

SOIL CONDITIONS.

The surface soil at the experiment farm is a sandy loam. At depths varying from 3 to 7 feet the loam is underlain by a stratum of Brule clay varying in thickness from 1 inch to 4 inches. This clay is extremely hard when dry, but it is not highly impervious to water. Under the clay the soil to great depths consists of a very fine sand. This sand is hard when dry, but when moist it is soft and friable.

RAINFALL.

As previously stated, the rainfall in western Nebraska is comparatively light during the fall and winter months. This is indicated in detail in Table I, which shows the precipitation in inches from October, 1910, to December, 1913, inclusive:

TABLE I.—*Precipitation in inches at the Scottsbluff Experiment Farm from October, 1910, to December, 1913, inclusive.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1910	......	......	......	......	......	......	......	......	......	0.31	0.05	0.28	......
1911	0.45	0.10	0	2.31	0.81	2.13	1.28	0.65	2.14	1.10	.08	.34	11.39
1912	.20	.60	1.27	3.72	1.66	1.61	2.45	2.77	2.70	1.16	.37	0	18.51
1913	0	0	.60	.13	3.72	1.71	1.30	4.33	1.18	.47	.11	.8	13.75

Table I shows that the total annual precipitation at the Scottsbluff Experiment Farm was 11.39 inches in 1911, 18.51 inches in 1912, and 13.75 inches in 1913. The average annual rainfall of the three years was 14.55 inches. The chief feature of the rainfall in connection with the fall-irrigation experiments is the quantity of precipitation which came during the autumn and winter months each year preceding the growing seasons of 1911, 1912, and 1913, when the crops used in these experiments were grown. The total precipitation from October 1, 1910, to April 1, 1911, amounted to 1.19 inches. From October 1, 1911, to April 1, 1912, the total precipitation was 3.59 inches, and from October 1, 1912, to April 1, 1913, it was 2.13 inches. The average total rainfall for this 6-months period during the three years was 2.3 inches, or a little less than 16 per cent of the average total annual rainfall during 1911, 1912, and 1913.

The above facts substantiate the statement previously made in connection with the low precipitation of the fall and winter months. Since much of this precipitation comes as small showers or as light snowfalls, a large proportion of the moisture is lost by evaporation from the surface soil, so that during the months from October to March, inclusive, comparatively little moisture is added to the soil by precipitation. This being true, soil which has given up the greater part of its available moisture to a field crop remains comparatively dry during the following winter.

The precipitation which came during the growing season of 1911, 1912, and 1913 could not be expected to influence greatly the results obtained with fall irrigation, since it fell on all the plats in the experiment and since irrigation water was applied uniformly to all the plats during the growing season. The chief point to be considered in connection with the rainfall as it affected the results of these experiments is that the fall and winter period was comparatively dry, the precipitation being insufficient to increase materially the quantity of moisture in the soil, particularly at depths of a foot or two below the surface.

METHODS OF EXPERIMENT.

Of the land used for these experiments one half was irrigated in the fall each year, and the other half was not so irrigated. In the fall irrigation, water was applied copiously to the soil, so as to saturate the latter to as great a depth as possible. This water was applied late in September or early in October each year, usually between September 15 and 30. In the fall of 1910 the land to be fall irrigated was plowed before irrigation, but it was found that this method necessitated considerable extra labor. In order to irrigate after plowing, the land had to be leveled, and after irrigation it was necessary to harrow the land in order to check evaporation. If irrigation water were applied before plowing, the leveling could be dispensed with. For this reason, in the fall of 1911 and again in the fall of 1912 the land was irrigated before plowing.

In the spring of each year crops were planted on the fall-irrigated land, and the same crops were planted on adjacent land not so irrigated. The spring and summer treatment of the land and crops was identical in both cases. Each crop was planted on the same date on both the fall-irrigated land and the land not so irrigated, and the irrigation during the growing season was uniform in both cases.

Irrigation was applied to the plats in both series by the usual methods. The potatoes, sugar beets, and corn were irrigated by means of furrows between the rows and the grain crops were irrigated by the field-flooding method. The water applied to the different plats was not measured, but irrigation was practiced in the way it is commonly done by good farmers in the locality. The water was allowed to flow over each plat so long as the soil absorbed it readily. In 1911, the only year in which soil-moisture determinations were made, it was found that at the first irrigation, June 10, the soil on the fall-irrigated land, Series VI, absorbed the irrigation water very readily. The soil was saturated to a depth of about 18 inches, and a good supply of water penetrated to a depth of 6 feet. Series VII, which was not fall irrigated, required a longer run of water in order to saturate the upper 18 inches of soil, and when this was done dry soil was found at a depth of 24 inches. After several attempts to apply additional water to Series VII and thus put moisture in the lower depths, the loss of water by run-off was so great that the flow had to be stopped. The results of the moisture studies made in 1911 are discussed later in this bulletin.

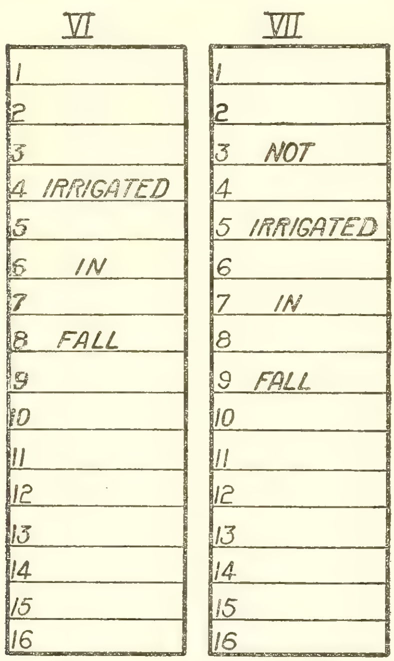

FIG. 1.—Diagram of Series VI and VII on field H, Scottsbluff Experiment Farm, where the experiments in fall irrigation were conducted.

The crops used in these experiments were wheat, barley, oats, potatoes, sugar beets, and corn. Corn was not included, however, until 1912, and only two years' results with this crop are available.

The experiments were conducted in field H, Series VI and VII, shown in figure 1. Series VI was fall irrigated each year and Series VII received no fall irrigation. The plats used were one-tenth acre in size. In 1911 there were on each of the series three plats each of wheat, barley, oats, potatoes, and sugar beets. In 1912 each series contained two plats of potatoes, two plats of corn, and three plats each of the four other crops. In 1913 there were on each series two plats of barley, two plats of potatoes, and three plats of each of the four other crops.

No attempt was made to conduct these experiments in definitely established crop rotations. The principal feature in the sequence of crops from year to year was that in most cases a cultivated crop followed an uncultivated one. For example, plat 2 in each series grew wheat in 1911, corn in 1912, and oats in 1913; and plat 11 in each series grew beets in 1911, wheat in 1912, and corn in 1913. The field on which these experiments were conducted was broken in the spring of 1910, so that all of the crops grown in 1911 were produced on virgin soil. The sequence of crops on the plats in both series during the years 1911, 1912, and 1913 is shown in Table II. Exactly the same sequence was used in Series VI as was used in Series VII; that is to say, for any given plat in Series VI in any one of the three years the corresponding plat in Series VII in the same year was planted to the same crop.

TABLE II.—*Sequence of crops in the plats in Series VI and VII, used for the fall-irrigation experiments at the Scottsbluff Experiment Farm in 1911, 1912, and 1913.*

Plat No.	Year and crop.			Plat No.	Year and crop.		
	1911	1912	1913		1911	1912	1913
1		Potatoes	Barley.	9	Oats	Barley	Beets.
2	Wheat	Corn	Oats.	10	Potatoes	Oats	Potatoes.
3	Barley	Beets	Wheat.	11	Beets	Wheat	Corn.
4	Oats	Barley	Beets.[1]	12	Wheat	Potatoes	Oats.[1]
5	Potatoes	Wheat	Potatoes.	13	Oats	Beets	Wheat.[1]
6	Beets	Oats	Corn.	14	Potatoes	Barley	Beets.
7	Wheat	Corn	Oats.	15	Barley	Oats	Corn.[1]
8	Barley	Beets	Wheat.	16	Beets	Wheat	Barley.

[1] These plats were used for a special experiment in 1913, and the yields of the crops are not considered in this report.

Table II shows that with the exception of plats 4, 9, and 15, an intertilled crop (potatoes, corn, or beets) was grown in alternation with either wheat, oats, or barley during the 3-year period.

RESULTS OF EXPERIMENTS.

A discussion of the cultural treatments applied and of the results secured in the fall-irrigation experiments during the 3-year period is given in the pages that follow.

WHEAT.

Defiance spring wheat was used in these experiments and was planted with a press drill at the rate of 6 pecks per acre each year.

In 1910 the land in both series was plowed during the first week in September. Both series were harrowed and leveled after plowing. On September 15 Series VI was irrigated. After the irrigation it seemed advisable to harrow Series VI for the purpose of checking evaporation, and in order to preserve uniformity both series were harrowed at the same time. In the spring of 1911 the land was prepared for seeding by harrowing and leveling. The wheat was seeded on March 31. On Series VII, which had not been irrigated the preceding fall, the soil was very dry at planting time in the spring of 1911 and the grain was very slow to germinate. After the rains, which came during the latter part of April, however, the grain came up promptly and a good stand was secured on both series.

The wheat plats in the two series were irrigated uniformly twice during the season of 1911. No differences were noted in the time of maturity of the wheat on the two series. The crop reached maturity on August 10.

In 1911 Series VI was irrigated on September 29 and 30. As soon as the soil was sufficiently dry in Series VI both series were plowed to a depth of about 7 inches. They were left in a rough condition during the winter. It is believed that leaving the soil in the rough condition had the effect of preventing much of the soil drifting which commonly occurs when the soil is left in a finely pulverized state during the winter months. As previously stated, the total precipitation from October 1, 1911, to April 1, 1912, was 3.59 inches, which was more than that which fell during the corresponding period in either the preceding or the following year. This relatively high precipitation left the soil on the series not irrigated in the fall in better condition at spring planting time in 1912 than at the corresponding time in 1911. When spring operations were begun in 1912, the surface soil on both series was in excellent condition for receiving the seed, and it was expected that there would be little, if any, difference in the yields obtained on the two series during that year. The two series were double-disked, harrowed, and leveled preparatory to seeding, and the wheat was planted on April 10. Uniform treatment was applied to the two series as in 1911. Both series were irrigated twice. No difference was noted in the time of maturity of the wheat on the two series. The crop on all the plats ripened August 2.

In 1912 Series VI was irrigated on September 29 and 30. As soon as the soil was sufficiently dry in Series VI both series were plowed and left in a rough condition over winter. The preparation for planting in the spring of 1913 was the same as that in 1912. The wheat was planted on April 4. The soil was in good condition at the time of planting and copious rains in April resulted in a uniform germination of the grain on all the plats. The irrigation and other treatments subsequent to planting were uniform on both series during the growing season. Both series were irrigated twice. All the wheat ripened about the same time, July 30.

The numbers of the plats, the height of the wheat at maturity, the yields of straw and of grain, and the number of pounds of straw accompanying the production of each bushel of grain during the three years are given in Table III. The plat numbers were the same in each series each year. In other words, where plats 5, 11, and 16 in Series VI were fall irrigated, the corresponding plats in Series VII grew the same crops and were otherwise treated in the same way, except that they received no fall irrigation. In studying the table it is necessary to keep this in mind and to remember that the figures in columns headed "VI" relate to the fall-irrigated plats, while those in the column headed "VII" relate to the plats which were not fall irrigated.

TABLE III.—*Results obtained with wheat on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1911, 1912, and 1913.*

Year and plat.	Height (inches).		Yield per acre.				Pounds of straw per bushel of grain.	
			Straw (pounds).		Grain (bushels).			
	VI.	VII.	VI.	VII.	VI.	VII.	VI.	VII.
1911.								
Plat 2	29	28	3,520	2,940	31.1	22.6	113.2	130.1
Plat 7	31	29	3,220	2,640	31.3	21.0	102.8	125.7
Plat 12	31	28	3,020	3,170	32.1	23.8	94.1	133.2
Average	30	28	3,253	2,916	31.5	22.4	103.3	130.2
1912.								
Plat 5	40	36	3,910	3,410	45.5	46.9	85.9	72.7
Plat 11	42	38	3,080	2,250	40.7	35.9	75.7	62.9
Plat 16	40	37	2,720	3,760	38.7	32.4	70.3	116.0
Average	40	37	3,236	3,140	41.6	38.4	77.8	81.8
1913.								
Plat 3	36	37	1,640	1,200	26 3	20.6	62.4	58.2
Plat 8	39	38	1,750	2,060	27.5	25.0	63.6	82.4
Average	37	37	1,695	1,630	26.9	22.8	63.0	71.5
Average results, three years	35.8	34.1	2,728	2,562	33.3	27.8	81.9	92.1
Difference in favor of fall irrigation	+1.7		+166		+5.5		−10.2	

Table III shows that the average results obtained with wheat during each of the three years favored fall irrigation. There were several individual instances in which the results did not agree with the average results, but the inconsistencies were in all cases relatively small. Considering the average results during each of the three years, the wheat on fall-irrigated land grew taller and produced heavier yields of straw and of grain and a lower proportion of straw to grain than the wheat on land which was not fall irrigated. Considering the average results of the 3-year period, the wheat on the fall-irrigated land grew 1.7 inches taller, produced 166 pounds more of straw, 5.5 bushels more of grain per acre, and 10.2 pounds less straw per bushel of grain than the wheat on the land which was not fall irrigated.

BARLEY.

The soil treatment applied to the plats which produced barley was substantially the same as that applied to the wheat plats during the three years. Plowing and other operations necessary in preparing the seed bed were the same on the barley plats as on the wheat plats, and fall irrigation was applied at the same time each year. A variety of barley known as California Feed was used during each of the three years, and it was seeded at the rate of 7 pecks per acre.

In the spring of 1911 the barley was planted on April 20. At this time the surface soil on both series was very dry, and very little seed germinated until after a rain of 0.35 inch which came on May 2. This rain supplied sufficient moisture to the fall-irrigated plats, but was not sufficient to germinate the grain on Series VII, where no fall irrigation had been applied. The barley on Series VII did not come up until after a heavy rain on May 15. After this rain the barley on both series grew well. The first irrigation was applied to the barley plats on both series on June 12. It was noted that the soil on Series VII absorbed moisture much less rapidly that that on Series VI and that the depth to which the irrigation water penetrated was somewhat greater on Series VI than on Series VII. The barley in both series was irrigated the second time on June 27. At this time the barley on the plats which had been fall irrigated showed the need of water much less than that on the plats on Series VI, but, in order to preserve uniformity, all plats were irrigated. The barley was irrigated twice during the season. The grain on both series matured on July 26.

In the spring of 1913 soil conditions at planting time were much more favorable than in 1911. This apparently was due to the relatively high rainfall of the preceding autumn, as was mentioned in connection with wheat. The seed was planted on April 24. The barley on both series germinated well and good stands were secured. The plats were irrigated twice during the season. The grain on both series matured July 30.

In the spring of 1912 barley was planted on both series on April 28. The soil conditions were fairly favorable. There was sufficient moisture in the soil to germinate the seed and support early growth. The plats in both series were irrigated twice during the season. The grain ripened on both series on July 28.

The numbers of the plats, the height of the barley at maturity, the yields of straw and of grain, and the number of pounds of straw accompanying the production of each bushel of grain during the three years are given in Table IV. The plat numbers were the same in each series each year. The figures in the columns headed "VI" relate to the fall-irrigated plats, while those in the columns headed "VII" relate to the plats which were not fall irrigated.

TABLE IV.—*Results obtained with barley on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1911, 1912, and 1913.*

Year and plat.	Height (inches).		Yield per acre.				Pounds of straw per bushel of grain.	
			Straw (pounds).		Grain (bushels).			
	VI.	VII.	VI.	VII.	VI.	VII.	VI.	VII.
1911.								
Plat 3	29	25	2,640	2,700	40.4	24.5	65.7	110.2
Plat 8	31	26	2,335	3,060	34.8	30.0	67.1	102.0
Plat 15	31	25	2,745	3,080	37.6	29.5	73.0	104.4
Average	30	25	2,573	2,936	37.6	28.0	68.4	104.9
1912.								
Plat 4	36	36	970	870	37.1	33.9	26.1	25.7
Plat 9	37	34	1,640	790	43.3	32.5	37.9	24.3
Plat 14	37	36	2,150	1,400	48.1	38.6	44.7	36.3
Average	37	36	1,586	1,020	42.8	35.0	37.1	29.1
1913.								
Plat 1	30	32	1,340	1,380	29.1	27.0	46.0	51.1
Plat 16	32	32	1,720	1,430	31.8	26.8	54.1	53.4
Average	31	32	1,530	1,405	30.4	26.9	50.3	52.2
Average results, three years	32.5	30.7	1,896	1,787	36.9	29.9	51.4	59.8
Difference in favor of fall irrigation	+1.8		+109		+7.0		−8.4	

Table IV shows that the average yields obtained with baleey during each of the three years were in favor of fall irrigation, and the same was true with all but one of the individual grain yields obtained. Barley on fall-irrigated land produced higher average yields of straw per acre each year, except 1911. In 1911 and 1912 the barley grew somewhat taller on the fall-irrigated land, but in 1913 the height of the matured grain was slightly greater on the land which was not fall irrigated. The average proportion of straw to grain was lower on the fall-irrigated land in 1911 and 1913 and higher in 1912. Considering the average results of the 3-year period, the barley on fall-irrigated land was 1.8 inches taller than that on land not fall irrigated, and it produced 109 pounds more of straw and 7 bushels more of grain per acre and 8.4 pounds less of straw per bushel of grain.

OATS.

The soil treatment and fall irrigation applied to the plats producing oats were the same as those applied to the plats producing wheat and barley during the 3-year period. A variety of oats known as "New Market" was used each year, and the seed was planted at the rate of 10 pecks per acre.

In 1911 the condition of the soil at planting time, April 20, was the same on the oats plats as on the barley plats, and the seed on both series was slow to germinate. The rains, which came on May 2 and May 15, however, added sufficient moisture to the soil to start a good stand on both series. The oats were irrigated twice during the season. No difference was noted in the time of maturity, the grain on all the plats having ripened on July 26.

In the spring of 1912 the soil was in excellent condition when the oats were planted on April 24, and good stands were secured on both series. The oats were irrigated twice during the season. No differences were noted between the two series until the grain began to head. From this time on the crop on the fall-irrigated plats was more vigorous than on the plats which had not been fall irrigated. The grain was ripe on both series on July 29.

In the spring of 1913 the oats on the fall-irrigated plats germinated much more promptly than those on the plats in Series VII. The germination on the plats which were not fall irrigated was very irregular, but the rains which came in the early part of May added sufficient moisture to the soil to produce satisfactory stands. The oats were irrigated twice during the season. The grain ripened about August 1 on both series.

The numbers of the plats, the height of the oats at maturity, the yields of straw and of grain, and the number of pounds of straw accompanying the production of each bushel of grain during the 3-year period are given in Table V. The plat numbers were the same in both series each year. In Table V, the figures in the columns headed "VI" relate to the fall-irrigated plats, while those in the columns headed "VII" relate to the plats which were not fall irrigated.

TABLE V.—*Results obtained with oats on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1911, 1912, and 1913.*

Year and plat.	Height (inches).		Yield per acre.				Pounds of straw per bushel of grain.	
			Straw (pounds).		Grain (bushels).			
	VI.	VII.	VI.	VII.	VI.	VII.	VI.	VII.
1911.								
Plat 4	40	40	3,380	2,610	66.2	40.3	51.1	64.8
Plat 9	40	38	3,350	3,280	62.5	53.7	53.6	61.1
Plat 13	38	36	3,790	3,640	76.8	55.0	49.3	66.2
Average	39	38	3,506	3,178	68.5	49.6	51.2	64.1
1912.								
Plat 6	41	42	2,920	2,230	65.6	55.3	44.5	40.3
Plat 10	44	44	4,920	3,630	113.0	96.0	43.5	37.8
Plat 15	42	42	4,670	3,790	105.2	94.1	44.4	40.3
Average	42	42	4,170	3,216	94.6	81.8	44.1	39.3
1913.								
Plat 2	43	42	3,000	1,910	84.3	76.5	35.6	24.9
Plat 7	45	42	3,620	2,100	101.2	97.5	35.8	21.5
Average	44	42	3,310	2,005	92.7	87.0	35.7	23.0
Average results, 3 years	41.9	40.8	3,656	3,521	83.8	72.8	43.6	48.4
Difference in favor of fall irrigation	+1.1		+135		+11.0		−4.8	

As shown in Table V, the individual yields of oats were in most cases higher on the fall-irrigated land, and the same was true with respect to the individual yields of straw. In 1911 the proportion of straw to grain was uniformly lower on fall-irrigated land than on land not fall irrigated, while the reverse was true in 1912 and 1913. Considering the average results of each year, the oats on the fall-irrigated land were taller in 1911 and 1913 and the same height in 1912; the average yield of straw per acre was higher on the fall-irrigated land in each of the three years, and the same is true with respect to the average yield of grain. Considering the average results of the 3-year period, oats on fall-irrigated land grew 1.1 inches taller, produced 135 pounds per acre more of straw, 11 bushels more of grain, and 4.8 pounds less of straw per bushel than oats on land not fall irrigated.

CORN.

Corn was included in this experiment in 1912 and 1913 only. The preparation of the land and the fall irrigation were the same as with the crops previously discussed. A local variety known as Calico corn was used. The seed was planted in rows 40 inches apart and the plants were thinned to 20 inches apart within the row.

In 1912 the corn was planted in both series on May 8. The crop was irrigated once during the season of 1912. No differences were noted as to the stage of maturity reached by the corn on the two series during the year. The crop was harvested on September 15, at which time the grain on all the plats was about 85 per cent matured.

In 1913 the corn was planted on May 19. During the period from July 7 to 12 severe hot winds prevailed and damaged the corn on both series to some extent. No differences were noted between the plats on the two series as to the damage done by the hot winds. The crop was irrigated once during the season. No differences were noted as to the stage of maturity reached before frost. The corn in both series was harvested on September 18, at which time it was practically all matured.

The numbers of the plats and the yields per acre of stover and of grain during the years 1912 and 1913 are given in Table VI.

Table VI shows that with one exception the individual grain yields of corn were higher each year on the fall-irrigated land. Considering the averages obtained in each of the two years, the yields of stover and of grain were higher on fall-irrigated land than on land not fall irrigated, and the proportion of stover to grain was lower on the fall-irrigated land. Considering the average results of the two years, the corn on fall-irrigated land produced 490 pounds per acre more of stover, 10.6 bushels per acre more of grain, and 5.4 pounds less of stover per bushel of grain than the corn on land which was not fall irrigated.

TABLE VI.—*Results obtained with corn on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1912 and 1913.*

Year and plat.	Yield per acre.				Pounds of stover per bushel of grain.	
	Stover (pounds).		Grain (bushels).			
	VI.	VII.	VI.	VII.	VI.	VII.
1912.						
Plat 2	4,400	4,650	57.2	52.7	76.9	88.2
Plat 7	3,700	3,100	47.2	44.9	78.4	69.0
Average	4,050	3,875	52.2	48.8	77.5	79.4
1913.						
Plat 6	4,000	4,100	70.0	56.4	57.1	72.7
Plat 11	4,850	3,040	62.1	40.0	78.1	76.0
Average	4,425	3,570	66.0	48.2	67.0	74.1
Average results, 2 years	4,212	3,722	59.1	48.5	71.3	76.7
Difference in favor of fall irrigation	+490		+10.6		−5.4	

SUGAR BEETS.

The soil treatment for sugar beets was the same as that previously described in connection with the other crops in this experiment. Sugar beets were planted in 1911, 1912, and 1913.

In 1911 the beets were planted on April 30. At this time the soil on Series VII, which was not fall irrigated, was so dry that none of the seeds germinated until about May 20. At this time heavy winds caused considerable soil drifting, which so damaged the crop on Series VII that the stand was reduced to such a point as to be considered a failure. It was too late to reseed, and sugar beets were therefore discarded for the year 1911.

In 1912 the beets were planted on April 27 in rows 20 inches apart, the seed being planted at the rate of 15 pounds per acre. Soil drifting again destroyed the stands, and the plats were reseeded during the second week in May. A good stand was secured from the second seeding. The beets were irrigated three times during the season.

In 1913 the beets were planted on May 20 in rows 20 inches apart, the seed being planted at the rate of 17 pounds per acre. The plants were thinned to 12 inches apart in the row. The crop was irrigated three times during the season. The numbers of the plats and the yields per acre obtained during 1912 and 1913 are stated in Table VII.

Table VII shows that the average yield of sugar beets was higher each year on the fall-irrigated land than on the land which received no fall irrigation. The average results of the two years show an increase of 1.6 tons per acre in favor of fall irrigation.

TABLE VII.—*Results obtained with sugar beets on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1912 and 1913.*

Year and plat.	Yield per acre (tons). VI.	VII.
1912.		
Plat 3	13.4	13.1
Plat 8	11.0	8.6
Plat 13	12.3	12.6
Average	12.2	11.4
1913.		
Plat 9	11.2	8.3
Plat 14	11.6	9.5
Average	11.4	8.9
Average results, 2 years	12.3	10.7
Difference in favor of fall irrigation	+ 1.6	

POTATOES.

The preparation of the land for potatoes was substantially the same as that for the crops previously discussed. Early Ohio potatoes were used. The seed was planted in rows 42 inches apart, with the hills 15 inches apart in the row.

In 1911 the potatoes were planted during the second week in May. The plants came up promptly on both series and made good growth until July 3. At this time a disease known as leaf-roll attacked them and in less than two weeks the entire crop was destroyed, so that no yields were secured in 1911.

In 1912 the potatoes were planted during the second week in May. At the time of planting, the surface soil contained an abundance of moisture and an excellent stand was secured on both series. During the growing season no important differences were apparent between the two series. The crop was irrigated three times during the season.

In 1913 the potatoes were planted on May 30. Good stands were secured and no differences in the growth of the vines on the two series were noted during the season. The plats in both series were irrigated uniformly twice during the season. The numbers of the plats and the yields per acre in 1912 and 1913 are stated in Table VIII.

As shown in Table VIII, no important differences, either in the individual yields or in the average yields, were obtained with potatoes. Considering the average results obtained during each of the two years, the yields were slightly higher on the fall-irrigated land, but the differences were insignificant.

TABLE VIII.—*Results obtained with potatoes on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm in 1912 and 1913.*

Year and plat.	Yield per acre (bushels).	
	VI.	VII.
1912.		
Plat 1	120.0	118.0
Plat 12	122.0	121.0
Average	121.0	119.5
1913.		
Plat 5	137.0	129.0
Plat 10	120.0	121.0
Average	128.0	125.0
Average results, 2 years	124.5	122.2
Difference in favor of fall irrigation	+2.3	

SUMMARY OF ALL CROPS.

The more important figures previously given in connection with the six crops included in the experiment are briefly summarized in Table IX. This table states the number of years results have been secured with each crop, the number of plats which have been devoted to each crop during the period, the average yields of potatoes and sugar beets, and the average grain yields of the grain crops. The differences in favor of fall irrigation are also stated. In order to show the relative effect of fall irrigation on the six different crops, the yields given in the first part of the table are stated in percentages in the last three columns, where the yields obtained on the land which was not fall irrigated are considered as 100 per cent in each case. As in the preceding tables, the figures in the columns headed "VI" relate to fall-irrigated land and those in the columns headed "VII" relate to the land which received no fall irrigation.

TABLE IX.—*Average and relative yields of six crops on fall-irrigated land (Series VI) and on land not fall irrigated (Series VII) at the Scottsbluff Experiment Farm.*

Crop.	Number of years.	Number of of plats.		Unit of yield.	Average yield per acre.			Relative yield per acre (per cent).		
		VI.	VII.		VI.	VII.	Gain by fall irrigation.	VI.	VII.	Gain by fall irrigation.
Wheat	3	8	8	Bushel	33.3	27.8	5.5	119	100	19
Barley	3	8	8	...do	36.9	29.9	7.0	123	100	23
Oats	3	8	8	...do	83.8	72.8	11.0	115	100	15
Corn	2	4	4	...do	59.1	48.5	10.6	122	100	22
Sugar beets	2	5	5	Ton	12.3	10.7	1.6	115	100	15
Potatoes	2	4	4	Bushel	124.5	122.2	2.3	102	100	2
All crops								116	100	16

As shown in Table IX, the average yields of all six crops were higher on fall-irrigated land than on land which was not fall irrigated, the average increase having been 16 per cent.

SOIL-MOISTURE STUDIES.

The soil-moisture conditions on the three wheat plats in each series were studied during the season of 1911. A 6-foot boring was taken

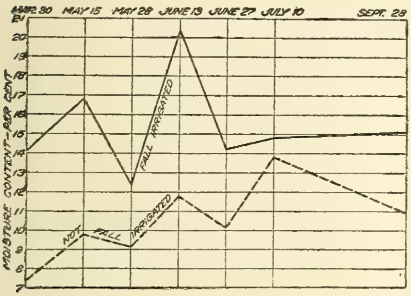

FIG. 2.—Average moisture content of soil to a depth of 6 feet on three wheat plats on fall-irrigated land and three wheat plats on land not fall irrigated at the Scottsbluff Experiment Farm, 1911.

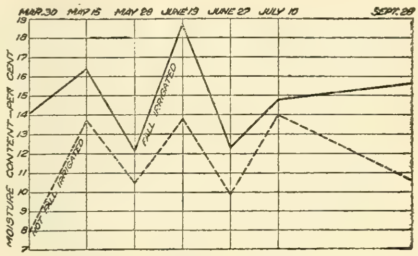

FIG. 3.—Average moisture content of soil to a depth of 3 feet on three wheat plats on fall-irrigated land and three wheat plats on land not fall irrigated at the Scottsbluff Experiment Farm, 1911.

from each of the three plats in each series seven times during that season, and the moisture content of each 1-foot section of soil was determined. The wheat plats on both series were irrigated twice during the season of 1911, on June 10 and July 5 and 6, and the plats in Series VI had been irrigated in the fall of 1910, as previously stated.

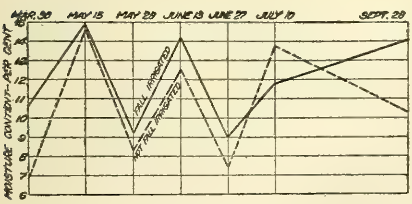

FIG. 4.—Average moisture content of surface foot of soil on three wheat plats on fall-irrigated land and on three wheat plats on land not fall irrigated at the Scottsbluff Experiment Farm, 1911.

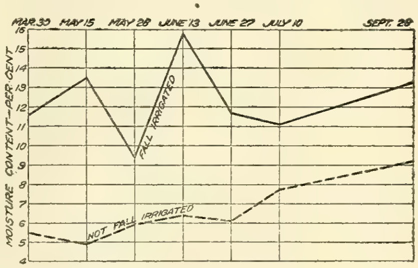

FIG. 5.—Average moisture content of the sixth foot of soil on three wheat plats on fall-irrigated land and on three wheat plats on land not fall irrigated at the Scottsbluff Experiment Farm, 1911.

The moisture content of the soil on the seven sampling dates is shown in figures 2, 3, 4, and 5. The average moisture content of the first 6 feet is shown in figure 2 and that of the first 3 feet in figure 3, while figures 4 and 5 show the moisture content of the first foot and sixth foot, respectively.

As shown in figure 2, the average moisture content of the first 6 feet of soil was higher throughout the season on the fall-irrigated land than on the land that was not fall irrigated. The difference was about 7 per cent on March 30 and May 15, about 3 per cent on May 28, more than 8 per cent on June 13, 4 per cent on June 27, 1 per cent on July 10, and 4 per cent on September 28. That these differences in the average moisture content of the first 6 feet were due mainly to the relative dryness of the lower portion of the 6-foot zone of soil on the land not fall irrigated can be seen by an examination of figures 3, 4, and 5.

Figure 3 shows the average moisture content of the first 3 feet on the two series. It is seen that the fall-irrigated land had more moisture in the upper 3 feet of soil than the land not fall irrigated, but the differences were decidedly less than those obtained where the upper 6 feet were considered, except on March 30, when the difference was nearly as great as that shown in figure 2.

As shown in figure 4, the moisture content of the upper foot of soil was very nearly the same on both series throughout the season, but the fall-irrigated land contained somewhat more moisture on all the sampling dates except July 10.

Figure 5 shows the moisture content of the sixth foot of soil during the season of 1911. It is seen that the sixth foot of soil on the land not fall irrigated was comparatively dry throughout the season. It contained about 5 per cent of moisture on March 30, and this moisture content increased to about 9 per cent by September 28. The sixth foot of soil on the fall-irrigated land contained nearly 12 per cent of moisture on March 30, and about the same on September 28.

A study of these four figures leads to the following conclusions: (1) The irrigation water applied in the fall supplied abundant moisture to the soil to a depth of at least 6 feet, while the land not fall irrigated remained relatively dry during the following winter. (2) The irrigation water applied during the season of 1911 percolated to the lower depths in the moist soil of the fall irrigated land more rapidly than in the relatively dry soil of the land not fall-irrigated. (3) The more favorable soil-moisture conditions on the fall irrigated land during the growing season were due chiefly to the fact that on that land the soil was well supplied with moisture at the beginning of the season.

SUMMARY.

(1) In many sections of the Great Plains area a comparatively small proportion of the annual precipitation comes during the period from October to March, inclusive, and the result is that the soil is frequently too dry at planting time in the spring to promote germination and support an early growth of spring-planted crops.

(2) Experiments were started in the fall of 1910 at the Scottsbluff Experiment Farm to determine whether fall irrigation of the land would improve the soil-moisture conditions and result in better yields of field crops.

(3) These experiments included wheat, oats, barley, potatoes, sugar beets, and corn. Three years' results have been obtained with wheat, oats, and barley, and two years' results with potatoes, sugar beets, and corn.

(4) With very few exceptions, higher yields of each crop were obtained each year from the land which was fall irrigated than from adjacent land which was not fall irrigated. Considering the average results of three years, fall irrigation increased the yield of wheat 19 per cent, of barley 23 per cent, and of oats 15 per cent. In the average results of two years, fall irrigation increased the yield of corn 22 per cent, of sugar beets 15 per cent, and of potatoes 2 per cent. The average increase in the yield of the six crops on fall-irrigated land was 16 per cent.

(5) With the exception of potatoes, the yields of all the crops were increased by fall irrigation sufficiently to more than pay for the cost of the fall irrigation.

(6) Soil-moisture studies made on the wheat plats in 1911 showed that the fall-irrigated land contained more soil moisture to a depth of 6 feet throughout the season than the land not fall irrigated. The greatest differences in soil moisture were found in the lower depths of soil, particularly the sixth foot, which contained from 3 to 9 per cent more moisture on the fall-irrigated land than on the land not fall irrigated.

(7) The difference in soil-moisture content during the growing season appears to have been due to the fact that the land which was not fall irrigated was comparatively dry at planting time in the spring and that it consequently absorbed water less readily than the fall-irrigated land, which was well supplied with moisture at the beginning of the season.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 134

Contribution from the Bureau of Entomology, L. O. Howard, Chief.
October 7, 1914.

(PROFESSIONAL PAPER.)

CITRUS FRUIT INSECTS IN MEDITERRANEAN COUNTRIES.[1]

By H. J. Quayle.

THE MEDITERRANEAN FRUIT-FLY.[2]

Ceratitis capitata Wied.

OCCURRENCE.

In the Mediterranean countries the Mediterranean fruit-fly (*Ceratitis capitata* Wied.) was first recorded from Spain in 1842, from Algeria in 1859, from southern Italy in 1870, from Sicily in 1882, from Tunis in 1885, from Malta in 1893, from Egypt in 1904, and from France in 1900.[3] This chronology, however, does not necessarily represent the spread of the insect, for it may have occurred in some of the countries long before any published record appears. In addition to the countries enumerated it is also said to occur in Asiatic Turkey. In the Mediterranean vicinity it is recorded from the Azores, Madeira, and Cape Verde Islands. The writer has taken this insect at Valencia

[1] This paper is of immediate value on account of the important information it contains bearing on the subject of the need of regulating the entry of citrus and other fruits imported from Mediterranean countries to prevent the entry of the Mediterranean fruit fly into the United States. The investigations embodied in this paper were made by Prof. Quayle during the summer of 1913 as a collaborator of the Federal Horticultural Board of this Department. Prof. Quayle is an expert on citrus insects and has previously made important studies in this field in California in connection with the State experiment station. Advantage was taken of the fact that he was proposing to use his sabbatical year to make a world-wide survey of citrus insects to commission him to make a much-needed preliminary survey of the citrus and other fruit insects in Mediterranean countries, more particularly in relation to the export fruit to the United States.

The fruit-fly conditions of the principal Mediterranean citrus districts was the important subject; the report, however, includes data on other fruit insects which ought to be considered in relation to any proposed regulation of the entry of fruits from countries covered.

As having an important bearing also on the possibility of the entrance of the fruit fly with Mediterranean fruit, the investigation includes a report on harvesting and marketing conditions of citrus fruit, more particularly as to methods of picking, sorting, curing, and shipping.

This paper indicates very clearly that there is little danger of fruit-fly introduction from the lemon, which is the main citrus importation from Mediterranean countries. That there is some danger from oranges and certain other fruits at particularly favorable seasons of the year has also been clearly brought out.—C. L. Marlatt, *Chairman Federal Horticultural Board.*

[2] Italian, *Mosca della arance;* Spanish, *Mosca.*

[3] For these and other facts, including a full bibliography of *Ceratitis capitata*, see Quaintance, A. L., U. S. Dept. Agr., Bur. Ent., Circ. no. 160, 25 p., 1 fig., Oct. 5, 1912.

and Barcelona, Spain (also punctured oranges in the London markets from Murcia, Spain), at Marseille, France, throughout southern Italy and Sicily, and punctured oranges in the markets of Jerusalem, Palestine.

FOOD PLANTS AND INJURY.

In Spain, during July, 1913, the Mediterranean fruit-fly was found in peaches and oranges, but in very limited numbers. The extent of infestation in peaches, its favorite food, amounted to only a fraction of 1 per cent. It is true that most of the peaches had not yet matured, and there is no doubt that a heavier infestation occurred later in the season. Many of the pears, apples, and other fruits were examined, both in the market and in the field, but none was found infested at that

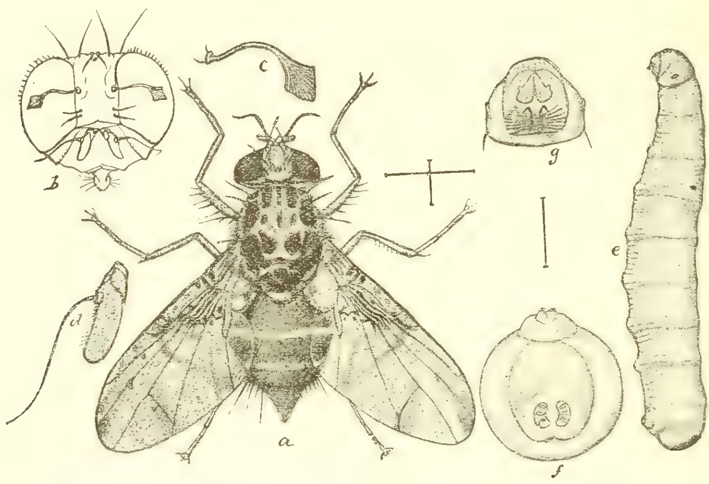


FIG. 1.—The Mediterranean fruit-fly (*Ceratitis capitata*): *a*, Adult fly; *b*, head of same from front; *c*, spatula-like hair from face of male; *d*, antenna; *e*, larva; *f*, anal segment of same; *g*, head of same. *a*, *e*, Enlarged; *b*, *g*, *f*, greatly enlarged; *c*, *d*, still more enlarged. (From Howard.)

time. Figs, which would probably be infested, were immature, as it was then in the period between the first and second crops.

During the month of March an extensive examination of oranges in the field and in packing houses was made, but at that season none was infested. It was learned that occasional complaints of infested oranges occur at the close of the shipping season during the last of June and the first of July, and again in a few of the earlier ripening fruits in October. When the section was again visited, in July, all of the crop was harvested, but scattering fruits on the trees and on the ground were common. These would be the ones likely to be infested were the fruit-fly present. After a week's examination in the groves around Valencia, only four oranges were found with the larvæ (fig. 1, *e*) of the fruit-fly. It is probable that the fly was unusually rare in 1913, because no complaint of infested fruit was recorded from any of the late shipments, and also because of the extreme scarcity of the fly as found by the writer in other fruits, as well as in oranges.

In Sicily *Ceratitis capitata* has been reared by the writer from the following fruits: Apple, azarole, fig, Indian fig, lemon, mandarin, nectarine, orange (sweet), orange (bitter), peach, pear, and plum. Of these fruits the peach is the most severely infested. This is particularly true of the late peaches in August and September. In many places much of the fruit as it approached maturity was attacked. As a consequence most of the fruit is picked rather green and not so many of the infested fruits find their way to the markets. In some sections, however, the fruit-fly was not so abundant in the field, and it was possible to get a good percentage of sound, mature fruit. Wormy fruit was supposed not to be sold in the markets of Palermo, and this was enforced by a few 50-lire fines. After the first few days following the hatching of the larvæ infested peaches are readily distinguished, and the writer was able to get all the infested fruit necessary for experimental purposes from the Palermo markets.

All of the peaches met with in Sicily were clings and of a very firm texture. The preponderance of such a variety may be due to the fact that such fruits do not break down so readily from the attacks of the fly. Figs are also more or less infested, but to no such extent as the peach, and the loss to the figs was very little. Most of the figs are picked for drying while they are still firm, and few in this condition contained larvæ. Plums and apples were rarely infested, while a few larvæ were found in pears. The pears of Sicily are likewise of solid, firm texture, there being no Bartlett or other representatives of our better varieties. Indian figs, a very common fruit in all parts of Sicily, were not infested until September, and then only a small percentage. It was not difficult to find azaroles containing larvæ, but the greater percentage of them was sound.

Aside from a few localities where considerable injury is done to the peach, the fruit-fly is not a very destructive pest in Mediterranean countries and fruit continues to be grown successfully in spite of its presence. In these countries, too, it should be noted, the growers have little knowledge of the insects infesting their fruit, with the exception of one or two species, and they do not, as a rule, practice any measures for artificial control. The writer knows of no case where the culture of any fruit in these countries has had to be abandoned because of the destructiveness of the Mediterranean fruit-fly. While this insect was on two or three occasions, during his sojourn in the Mediterranean vicinity, served to the writer through peaches at the table, codling-moth-infested apples and pears formed a regular part of the menu in comparison. These statements are made with no purpose of minimizing the importance of the pest.

INFESTATION OF ORANGES.

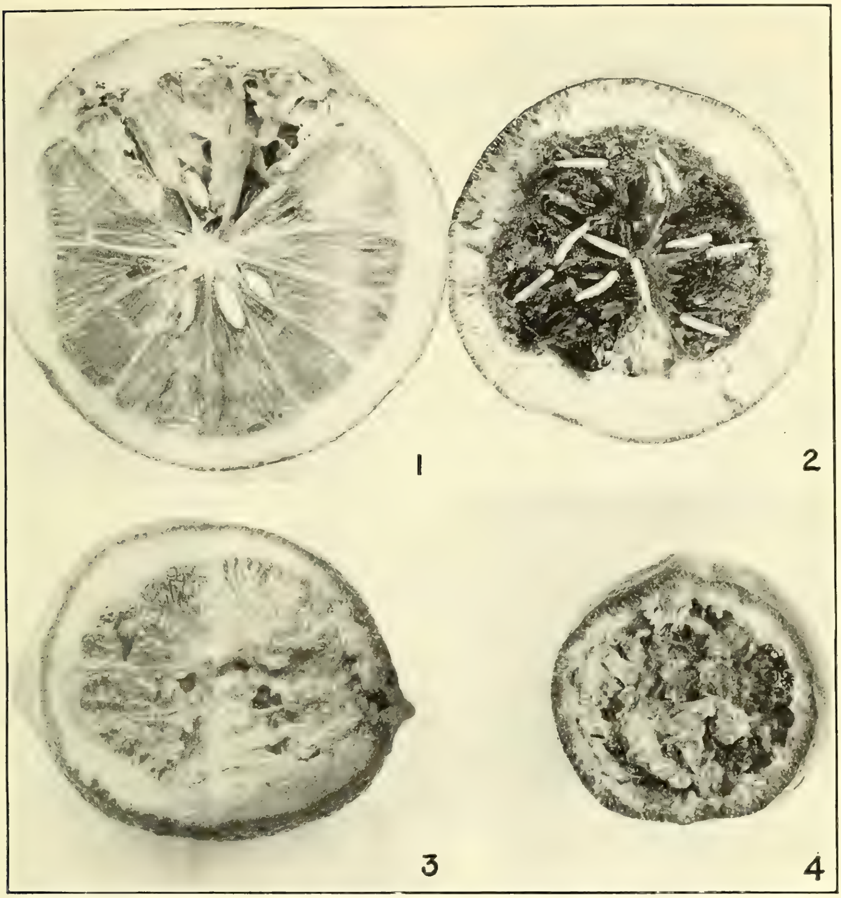
Oranges were not found infested with the fruit-fly during April and May. By the end of May oranges are almost entirely off the market in Sicily. Much orange fruit was examined during April and May, both on the Island of Sicily and on the mainland, but no infestation was found. In Calabria and at Messina oranges were seen with fruit-fly punctures from the previous season, but no larvæ were present. The eggs failed to hatch or the larvæ died immediately upon hatching without getting beyond the egg cavity. According to Dr. Martelli, entomologist at Messina, who has given considerable attention to the fruit-fly, oranges may usually be found infested by the 1st of June, but none was found with living larvæ anywhere, to the writer's knowledge, up to the second week in June of 1913.

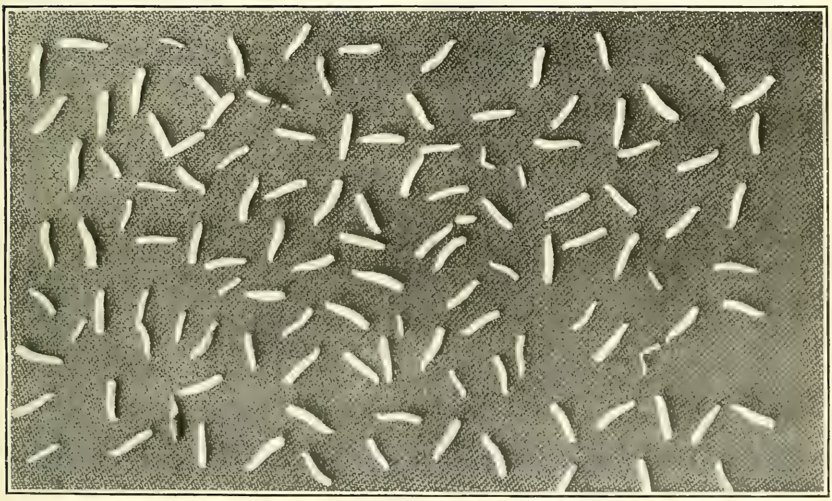
When the writer returned to Sicily on the 1st of August such ripe oranges as were still on the trees or on the ground were heavily infested with the fruit-fly (Pl. I, fig. 2). Indeed, no oranges could be found that were either not infested or did not show punctures. For some reason unaccounted for, a few oranges among an almost complete infestation will show from two or three to a dozen punctures, yet will remain sound and contain no larvæ. One orange taken late in August contained the remarkable number of 118 larvæ (Pl. I, fig. 5). These were mostly full grown, and the orange was below medium size. The pulp alone did not furnish sufficient food for such a number, so many of them had retreated to the denser rind, and it was necessary to cut this into very small pieces to disclose the larvæ, which were concealed in small burrows. This orange, before it was cut, was firm and undecayed.

The usual number found in oranges varied from 6 or 7 to 15 or 20. In peaches there were about the same number, but occasionally as many as 30 or 35. In figs usually from 3 or 4 to 8 or 10 were found, while in azaroles and plums, which are smaller, from 2 or 3 to 5 or 6 would be the usual numbers.

Both the sweet and bitter oranges were infested. The bitter orange, therefore, at least as it occurs in Sicily, is not objectionable as food to the fly. The pomelo, or grapefruit, is very rare in Sicily, as elsewhere in Europe, so that a fair test of possible infestation was not presented. A few old grapefruit, however, occurring on three or four trees that adjoined orange trees on which all the fruit was infested, showed no larvæ or punctures. Mandarins are, of course, commonly infested. (Pl. I, fig. 4.) Occasional ones, apparently remaining over from the previous year, were collected as late as August, and these were in nearly all cases infested.

The first oranges of the crop of 1913 with fruit-fly punctures were seen about the middle of September. This fruit had begun to turn yellow over a small area on one side, and the punctures were in this





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DAMAGE TO CITRUS FRUITS BY THE MEDITERRANEAN FRUIT FLY.

Fig. 1.—Lemon infested with *Ceratitis capitata*. Fig. 2.—Orange infested with *C. capitata*. Fig. 3.—Lemon infested with *C. capitata*. Fig. 4.—Mandarin infested with *C. capitata*. Fig. 5.—118 larvae of *Ceratitis capitata* from a single orange. All from Sicily. (Original.)

yellow area. The adult flies (fig. 1, *a*) were commonly seen walking about on the fruit looking for a suitable place for oviposition. By the last of September the fly was seen in considerable numbers where the fruit was beginning to ripen. In Sicily up to the last of September it was but rarely that a tree would be found with any of the fruit showing yellow. An occasional orange would be seen at this time almost entirely yellow, but these were not mature, for they were still very sour. Punctures were common on such fruit, as well as on some others almost entirely green, and as many as a dozen punctures were often seen in a small yellow area. Possibly the punctures were partly accountable for the yellowing. The flies were seen more commonly on the trees during the morning and evening. In the rearing cages during the hot weather they remained on the ground or out of the direct sunlight during the middle of the day.

A large number of punctured oranges were examined during the last of September. Not a single one was actually found infested with the larvæ. Ninety per cent of the punctures examined either contained no eggs or larvæ, or contained eggs that had failed to hatch or larvæ that were dead. The remainder contained eggs but recently deposited, or young larvæ that had just hatched and were still within the egg cavity. The reason for the absence of eggs in many of the punctures is probably that the fly, after making the puncture, found conditions unsuitable for oviposition. The presence of shriveled eggs or dead larvæ in the egg cavity must be due to the immaturity of the fruit. In a large majority of cases the eggs had hatched; in fact, only a few unhatched eggs were found.

In immature oranges there is often a formation of gum about the puncture. Green oranges were known to have punctures, in some cases, by the presence of small globules of gum on the surface. When these oranges were taken from the tree and opened they were found to contain eggs, or larvæ that had just hatched. Very soon a yellow spot occurs about the point of puncture, and the gum upon hardening is easily removed, and probably soon falls off naturally. A hard, gummy, granular tissue also forms around the egg cavity, and it is often possible to remove this ball of brown tissue with the egg cavity intact. It was at first thought that the formation of this tissue, by furnishing an impenetrable wall around the egg cavity or by compressing the eggs and larvæ within, was the direct cause of the insect's mortality. But this hard tissue is not formed to any extent before the eggs hatch. In practically all cases where living young larvæ were found, which indicated recent oviposition, the surrounding tissue was not appreciably hardened, although the brown color began to show.

The egg cavity is situated in the spongy layer of the rind, just below the outer covering containing the oil cells. The surrounding wall of gum seems to be formed from the outer layer, but soon extends into the spongy tissue and entirely surrounds the egg cavity. The number of larvæ found in the punctures in September was always large—from 20 to 30 or 40. Larvæ were seen closely massed together in the egg cavity, but although appearing perfectly normal they were inactive. In such cases death had occurred recently, for later they became brown and shriveled. Occasionally one or two would be seen to move slightly. In some cases two or three larvæ had made their way out of the egg cavity and penetrated a short distance into the spongy tissue. In no case, however, was the pulp reached. Why the larvæ perished within the egg cavity or soft spongy tissue is not definitely accounted for. It appears to be because of lack of air or through the action of some substance in the rind.

A large majority of the punctures in green oranges were seen to be entirely sealed by gum. The tendency of citrus fruits, or, in fact, any fruit, to exude gum to repair wounds while they are immature, is well known. The condition of the larvæ in the egg cavity—simply dying massed together as they hatched, with no evidence of any attempt to migrate—may indicate suffocation. While many larvæ occur in a single cavity, and the space is well occupied, death can hardly be accounted for through compression by growth of tissue or gum formation, because some of them, at least, could work their way out of the cavity. In cases where living larvæ were found, from 30 to 40 were seen in a single cavity with plenty of opportunity for migration.

That fruit-fly larvæ require considerable air was shown in the case of those that were transferred into a juicy lemon, where the entrance was completely closed by the posterior tip of the bodies of a half dozen or more of the larvæ. Numerous instances of the death of full-grown larvæ have been noted to take place in the exuding juices of fruit in glass jars. In peaches and other fruits, also, there are holes in the outer epidermis, made at first through oviposition and later enlarged and serving for the entrance of air.

Fruit-fly larvæ appear to live largely in decayed tissue; that is, the decay induced by them seems to precede the progress of the larvæ. It is possible that in green fruit this decay is not so readily induced. And here, again, the organisms of decay may be kept entirely out of the fruit if the entrance to the surface is effectually closed.

On September 24, 1913, 25 living young larvæ that had just hatched were taken from an egg cavity of the greenest orange found infested and placed through a hole in the rind into the pulp of the same orange. In another orange, also very green, a hole was made connecting the egg cavity with the pulp without disturbing the young larvæ in the cavity. In both cases openings were left to the surface. When the fruit was examined on October 3, partly grown larvæ were found in both of the oranges mentioned. Only a small percentage, however, had lived, although the number was sufficient to indicate that the pulp of the orange was not too green or too acid to serve as food. These oranges were perfectly green, there being no yellow whatever on one and only a slight tinge over a small area on the other. The inability of the larvæ to reach the pulp seems, therefore, to be due to an injurious substance in the rind, to lack of air, to decay, or to all three combined.

From examination of oranges in Italy, Sicily, and Palestine, as they are maturing in the fall, there appears to be no possibility of infestation until the fruit reaches maturity, even though eggs of the fruit-fly may be deposited. The practical bearing of this fact is important in greatly limiting the season of infestation. And in the Mediterranean countries visited, cold weather appears by the time the fruit is mature and susceptible to infestation, so that the season is very short in the autumn, and most of the fruit is harvested before the return of warm weather in the spring.

APPEARANCE OF FRUIT-FLY PUNCTURES IN ORANGES.

Immediately after the adult fruit-fly has oviposited in the orange the puncture is not readily distinguishable, but it soon appears as a brown or grayish, oval-shaped area about 0.5 mm. long, with a crack or opening in the center. In green oranges the area immediately around this may be yellow. Later this area may become brown and depressed. After some time also the point of puncture is indicated by a distinct conical elevation. These elevations are conspicuous on the surface of the fruit and they may at once be diagnosed as indicating punctures of the Mediterranean fruit-fly. In older fruit these conical elevations may arise from circular depressions which are of a brownish or yellowish color. If the outer layer containing the oil cells be cut away, the egg cavity will be disclosed in the spongy tissue. After some time brown and hard granular tissue usually surrounds the egg cavity, so that the whole may be removed from the surrounding tissue as a gall. To make sure that punctures are present the egg cavity should be examined for the egg skins, shriveled eggs, or larvæ. If the orange is infested, small burrows may be traced through the spongy layer to the pulp, and the pulp itself will be decayed. Typical punctures are at once distinguished, but their character and form vary so greatly that sometimes other scars or abrasions on the fruit may be mistaken for them.[1]

INFESTATION OF LEMONS.

The only supposed instance recorded of the occurrence of *Ceratitis capitata* in lemons in Sicily is a note by Prof. Inzenga in the Annali di Agricoltura Siciliana, Volume XIV, 1884, page 101. In

[1] Since the foregoing was written the writer has examined fruit-fly conditions in the Hawaiian Islands, where they are strikingly different from those in Mediterranean countries. The most evident difference in appearance of the fruit in Hawaii is the much more copious exudation of gum.

this article Prof. Inzenga simply states that a "small worm" was observed by Profs. Alfonso and Bonafede to breed in the orange, lemon, Indian fig, and other varieties of fruit. Prof. De Stefani,[1] of the Universitate di Palermo, questions, and rightly so, the authenticity of the statement, adding as proof that in all the writings of Profs. Alfonso and Bonafede no statement occurs to the effect that *Ceratitis capitata* breeds in lemons. Prof. De Stefani further calls attention to the fact that no entomologist (excepting the questionable case above) has ever observed Ceratitis to breed in lemons in Italy; and concluded with the statement that "It is excluded absolutely that *Ceratitis capitata* lives in the lemons in Sicily." (E. da excludersi assolutamente che la *Ceratitis capitata* viva nei lemoni di Sicilia.)

Dr. G. Martelli, who has made careful studies on *Ceratitis capitata*, published an article entitled "La Mosca della arance non vive nei nostri limoni" (The orange fly does not breed in our lemons), in the Giornale di Agricoltura Meridionali, No. 9, Ann. V, 1913, Messina. In a paper read before the R. Scuola Superiore di Agricoltura at Portici in January, 1913, Dr. Martelli records experiments in attempting to transfer the eggs of *Ceratitis* into the lemons. These experiments all resulted negatively, and he concluded that the insect would not live in lemons.

During April and May an extensive examination in all the sections of Sicily was made in the field, as well as in numerous field and exporters' packing houses, with the result that no evidence of infested lemons was found. This was the season when the heaviest shipments were being made to the United States, and it was felt that a thorough examination should be made at that time. But at that season no fruit-fly larvæ appeared in any other fruit, and thus negative evidence under such circumstances would be of little value. Consequently it was proposed that the inspection be continued at a later and more favorable season, and this was at once agreed to by Mr. Marlatt, chairman of the Federal Horticultural Board. Accordingly the writer returned to the Island of Sicily, where he remained throughout August and September.

As already intimated, there was abundant evidence of the presence of *Ceratitis capitata* in other fruits at that time. Field inspection was therefore resumed in the lemon groves of Sicily during the first week in August, and during the second week there was found the first evidence of the breeding of *Ceratitis capitata* in lemons. (Pl. I, figs. 1, 3.) The infested lemons were large, overripe ones, with more or less decay, and were found on the ground. The total number found during the week was four, all taken in the same grove. Near by were many old ripe oranges severely infested with the fly. The week following 10 more infested lemons were found; most of these

[1] Intorno ad Alcuni Insetti degli Agrumi del Prof. Teodosio De Stefani, Palermo, p. 6, 1913.

were taken in this grove, but four were taken in three other places. Two out of the 10 taken during the week were on the tree, while the remainder were on the ground. It should be stated that the two taken from the tree were also partly decayed on one side. The decay in most of these lemons appeared not to be due entirely to the fruit-fly. No punctures were seen, and it is assumed that the eggs were deposited in the decayed side, or else the decay which set in later completely obliterated the punctures. One more lemon with fruit-fly larvæ was found during the fifth week, making a total of 15 infested lemons out of the thousands examined. None was found during the remaining three weeks of the inspection. None of the infested lemons would have been considered for shipment, and with three or four exceptions would not have been taken for the by-product factory. In some of the lemons, it is true, the larvæ were nearly grown, and the condition of the fruit can not be vouched for at the time of oviposition, but in others the larvæ were but partly grown, and thus the fruit had not been long infested.[1]

EXPERIMENTS WITH THE FRUIT-FLY.

Through the kindness of the Prince of Galati use was had of a neglected garden within the city of Palermo, and under a tree here was equipped an improvised laboratory. (Pl. X, fig. 5.) Three series of experiments were carried on. The first series was to determine if it is possible to transfer the larvæ of Ceratitis from other fruits into the lemon and bring them to maturity. The idea was generally held in Italy, even by the entomologists, that the lemon is too bitter or acid for the fruit-fly. The second series was to determine the possible extent of oviposition on lemons in confinement, and the third as a check on the second series and for life-history work, and to determine the extent of breeding in other fruits, as the apple, pear, peach, and orange, under the same conditions.

To summarize briefly, the first series of experiments resulted in establishing the fact that it is possible to transfer fruit-fly larvæ from a fine ripe peach to a ripe and also to a perfectly green lemon and bring them to maturity. The second series, so far as the experiments were conducted in small glass containers, resulted negatively. The third series resulted in securing oviposition and development in the peach, pear, and orange.

In the first set of experiments a small plug was cut out of the rind of the lemon, and a small cavity made in the pulp, just large enough to contain the larvæ. After the larvæ were transferred, the plug of rind was replaced, a small triangular piece first being cut out of one side of the plug for air. Aseptic methods were employed

[1] In Hawaii a perfectly sound lemon has been seen with a single specimen of *Ceratitis capitata*. In Hawaii, also ,Ceratitis punctures in lemons are very common, though actual infestation seems to be rare.

in these operations, although not with entire success, to prevent infection from molds, which gave considerable trouble. In 12 experiments 163 larvæ were transferred into lemons, and 108, or 66.2 per cent, changed to pupæ and emerged. The time spent in the lemons varied from 2 to 10 days, with an average maximum of 7.7 days.

The length of the larval period was determined as 10 to 11 days. On this basis the age of the larvæ transferred varied from 1 or 2 to 10 days. It will be noted that not all the larvæ developed, 33.8 per cent having died from one cause or another. The molds in the fruit were probably the chief factor in the mortality. The exuding juice drowned a good many that were emerging for pupation, others were dead in the fruit, and possibly some were injured in the transfer. Enough, however, emerged to show that the lemon is not an impossible food for the larvæ of *Ceratitis capitata.*

In each of 48 glass jars from 1 to 2 lemons were placed and from 6 to 22 flies liberated. These were fed with sweetened water, and lived from 3 to 26 days, the large majority, however, dying after 6 or 7 days. No infested lemons resulted from these experiments and no punctures were found. Under the same conditions peaches, pears, and oranges became infested, but with these some of the experiments also resulted negatively. Apples in three jars were not infested. In only a few cases were flies seen in copulation, and it appeared that they were too closely confined and under too unnatural conditions for free breeding.

In four large breeding boxes, where infested fruit was placed on the ground and the flies allowed to emerge, a total of 56 lemons in all stages of ripeness was placed. In 2 of these boxes the fruit was first punctured with a needle or scalpel, and in the other 2 the lemons were sound. Some of the lemons remained in these boxes for 6 weeks. Hundreds of flies emerged in each of the boxes. The lemons, when examined, were in various stages, many being decayed. No infested fruit was found, and no punctures of the fruit-fly were seen in any of the lemons.

While these experiments were not, of course, extensive and adequate enough to establish any fact on negative evidence alone, they do show that oviposition in the lemon in Italy is not at all common.

PUPATION.

Ordinarily fruit-fly larvæ go into the soil to the depth of about an inch, or otherwise seclude themselves for pupation; but this is not at all necessary, and pupation may occur anywhere in the open and direct light. The side of a packing box or any other container of fruit is thus suitable for the purpose, and the fruit-fly may be transported in this manner.

LIFE CYCLE.

No extended life-history studies were attempted or possible in the time available, but such records as were kept indicate that the life cycle of Ceratitis is completed in 22 or 23 days in Sicily in August. Out of this total, 2 or 3 days are required for the eggs to hatch, 10 or 11 days for the development of the larvæ, and 10 days for the pupal period. Since these records were made during the warmest weather they represent the minimum time for development.

OTHER INSECTS IN ORANGES AND LEMONS LIKELY TO BE MISTAKEN FOR THE MEDITERRANEAN FRUIT-FLY.

The commonest insect occurring in decayed or overripe oranges and lemons on the ground, and also occasionally on the tree, is a nitidulid beetle, *Carpophilus dimidiatus* Fab. Larvæ and adults of this beetle often occur in great numbers. Usually decay has already set in before the fruit is attacked, but if it remains on the ground for some time the beetles will bore through the rind and they themselves cause decay. The appearance of such fruit is very much like that infested by Ceratitis. The larva of Carpophilus is about the same length as that of the fruit-fly, but is easily distinguished because it is beetle-like and both ends are tipped with brown. Instead of breaking down, lemons often dry with extremely hard, firm rind, and they remain in this condition for months. Such lemons occurring on the ground are, however, frequently infested with this beetle. The beetle enters the fruit where it rests on the ground by drilling holes through the firm rind.

Another common "worm" in decayed oranges and lemons is the larva of a fly, *Lonchaea splendida* Loew. This larva is more slender and of a paler color than that of the fruit-fly, but small specimens are very likely to be mistaken for fruit-fly larvæ; hence they must be examined closely and identified by the spiracles to make sure of the species. The adult fly is smaller than Ceratitis and is of a metallic blue color.

Larvæ of Drosophila also frequently occur in decayed oranges and lemons, but, except in possible cases of very small specimens, they are easily distinguished from the more robust and yellowish white Ceratitis larvæ. Of all the "worms" infesting oranges and lemons, Ceratitis larvæ are the most sluggish and slow moving, so that with a little experience they may be distinguished by their movements.

THE BLACK SCALE.[1]

Saissetia oleae Bern.

DISTRIBUTION AND INJURY.

The black scale is generally distributed throughout the Mediterranean citrus sections. (Fig. 2.) It varies in numbers from an occasional scale to numerous specimens forming a complete incrustation on the twigs and branches, and in injury from an insect of no commercial importance to one doing much damage through the quantity of sooty-mold fungus found on the trees and fruit.

In the most important orange section of the Mediterranean countries, that of Valencia, Spain, the black scale is, according to our standards of judging, entitled to rank first among the citrus fruit pests. This statement is at least true for the years 1912 and 1913. In all of the scores of packing houses visited during the month of March, 1913,

FIG. 2.—Distribution of insect enemies of citrus fruits in Mediterranean countries. (Original.)

from a half dozen to 15 or 20 women were seen washing fruit to remove the sooty-mold fungus occurring as a result of black-scale infestation. In some cases the sooty mold was due to the mealy bug (*Pseudococcus citri*), but infection from this source would amount to only a small percentage of the total. During July, 1913, when the section was again visited, numerous young were seen on the leaves, which, barring a heavy mortality later, would furnish the same conditions for the season following. In numerous groves around Burriana, Spain, the sooty-mold fungus was seen to form a complete coating over all the upper surface of the leaves, branches, and fruit, and such a severe incrustation of scales occurred as actually to kill many of the smaller twigs, and in some cases even the larger branches.

The greatest injury from the black scale was seen in the "Plana," or level district opening to the sea north of Valencia, and centering around Burriana. The conditions here are much the same as in the

[1] Spanish, *Escania negra;* Italian, *Cocciniglia dell' olivo.*

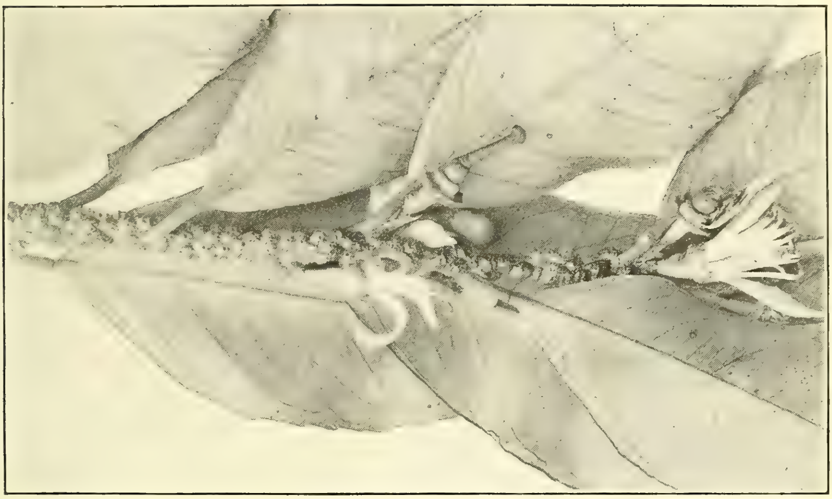

FIG. 1.—THE BLACK SCALE (SAISSETIA OLEAE) ON LEMON TWIG, SICILY. (ORIGINAL.)

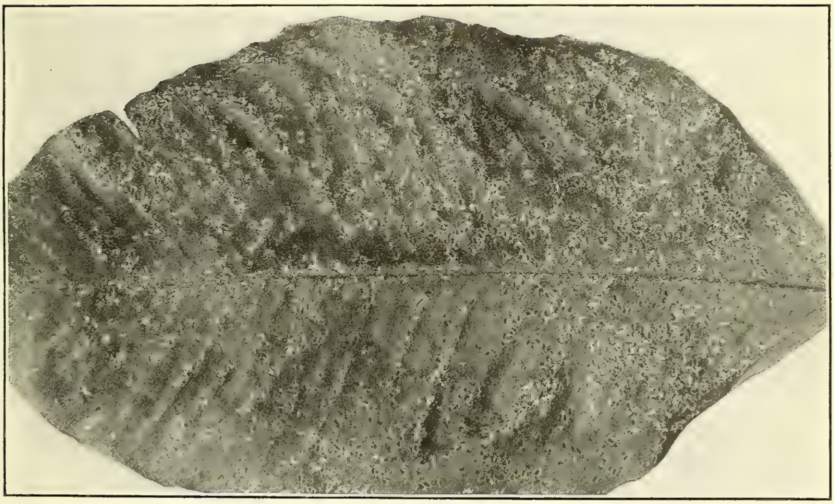

FIG. 2.—A COMMON CITRUS SCALE (PARLATORIA ZIZYPHUS) ON A LEMON LEAF, SICILY. (ORIGINAL.)

SOME SCALE INSECT ENEMIES OF CITRUS FRUITS IN SICILY.

coast counties in southern California, where the same scale is most important as a pest. The "Ribera," or section south of Valencia, is hilly and rolling and is separated from the sea by hills and mountains. The direct sea influence is, therefore, not so pronounced, and the black scale is not so generally injurious. The influence of the sea consists in moderating the effect of the summer heat, which, if too intense, results in a wholesale mortality of the young scales, in which stage the scale is largely found during the summer months.

The black scale is also more or less abundant in localities farther south, as Murcia, Malaga, and Seville. But in these sections, which are still farther removed from the sea, the black scale is not so important a pest as is *Crysomphalus dictyospermi*.

The washing of oranges in Spain consists in rubbing each individual fruit, first in wet, and then in dry sawdust, the latter both to hasten the drying and to complete the cleaning. It is not a bad system so far as results are concerned, and, with the low price of labor (20 cents a day for women), the expense is no greater and probably much less than with the use of machinery as with us. The sawdust method, however, leaves more traces of the mold in the small depressions of the fruit than does our machine with brushes. When attention was called by the writer to the absence of any aseptic agent in the water used in dampening the sawdust—and it is used over and over again—the reply was evoked that there is no better disinfecting agent than ordinary sea water. But the writer was not sure that sea water was being used, and he was very certain it was not in many places. The amount of fruit receiving the sawdust treatment varied from 25 per cent to more than 90 per cent in most of the packing houses visited.

The washing of the fruit, according to Spanish standards, is regarded simply as one of the regular practices of the packing house, and is not an expense generally attributed to the black scale or any other insect. In fact, no one was seen in Spain who considered that the sooty-mold fungus [1] was in any way related to the black scale. It was for this reason that the statement appears at the beginning of this discussion that the black scale is considered by the writer to be the most important pest in the Valencia section, "according to our standards." According to Spanish standards it is no pest at all, chiefly because the insect and its important effect, the sooty-mold fungus, are not generally considered as in any way related.

But the injury by the black scale in the Valencia section is not due entirely to the presence of mold on the fruit. When such severe infestations occur as were frequently seen, the tree itself suffers. Small twigs are killed, and the coating of mold over the leaf, branch, and fruit not only interferes with the functions of the tree, but the fruit itself is deficient in sweetness and flavor.

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[1] Spanish, *Negrilla*.

In Sicily the black scale was seen in great abundance in several places, but these places usually consisted of but a small area, or even but a few trees. (Pl. II, fig. 1.) It is found in scattering numbers throughout the citrus area, but with the exception of a few cases of dirty fruit which have been seen, coming from limited areas, as noted above, the black scale is not a serious pest in this, the most important lemon section of the Mediterranean. It is the writer's opinion that, above all other factors, the absence of the scale in serious numbers in Sicily is due to the sirocco, which frequently prevails there during the summer and fall. This is a burning hot, dry wind from the African deserts. It is only necessary to experience one of these siroccos, which usually lasts about three days, to conclude what effect it would have on insects not well adapted to withstand heat and dryness. Opportunity was afforded for judging the effects of a sirocco on young black scale in Sicily, with the result that between 95 and 100 per cent were seen to be killed. The same effect of hot weather has been observed by Mr. C. L. Marlatt,[1] Mr. R. S. Woglum,[2] and the writer [3] in California.

SEASONAL HISTORY.

So far as could be observed the black scale has very much the same life and seasonal history in Mediterranean countries as it has in California. The majority of the young appear in June and July. These settle almost entirely upon the leaves or on the tender twigs. It is during this period that high temperatures are likely to cause a heavy mortality. Later in the fall the young that still survive migrate to their permanent abode on the twigs and branches, and pass the winter as partly grown insects. During this season growth is very slow, but with the resumption of warm weather in the spring it proceeds rapidly. By May and June oviposition occurs, and from 2,000 to 3,000 eggs are deposited by a single female during a period of from 30 to 60 days. While the majority thus mature in the spring and require 8 or 10 months for development, others, that have all the heat of summer, will mature in 4 or 5 months, and thus some scales will be found in all stages at all seasons.

NATURAL ENEMIES.

The most important natural enemy of the black scale in most sections where it occurs is *Scutellista cyanea* Motch. It was a surprise, however, to find that this parasite occurred in less numbers in

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[1] Marlatt, C. L. Insect control in California. U. S. Dept. Agr. Yearbook for 1896, p. 217–236, Pl. V, 1897. See p. 218.

[2] Woglum, R. S. Fumigation investigations in California. U. S. Dept. Agr., Bur. Ent., Bul. 79, 73 p., 28 figs., June 11, 1909. See p. 12.

[3] Quayle, H. J. The black scale. Cal. Univ. Coll. Agr. Expt. Sta. Bul. 223, p. 151–200, 24 figs., 8 pl., July, 1911. See p. 165.

many of the Mediterranean countries than it does in California. In those countries where no artificial control is practiced it was thought that all natural enemies would be more abundant. On the other hand, no place was seen where the numbers equaled those of the California citrus belt, with a possible exception in the case of *Ceroplastes rusci* L. on the fig, in a few places in Sicily. In Spain, where the black scale was so abundant on citrus trees, very few were attacked by Scutellista. Where counts were made the maximum did not exceed 20 per cent, while hundreds of scales were examined in many places with no evidence at all of parasitism. Scutellista, like most insects, has its periods of increase and decrease, and the year 1913 may have been at the end of a depression. But during years when it occurs in fewest numbers in southern California it is much more abundant than it was observed to be in Spain in 1913. In Sicily, also, Scutellista was not seen in large numbers anywhere on the black scale on citrus trees.

Aside from Scutellista the only other enemies of any importance noted were two coccinellids, *Chilocorus bipustulatus* L. and *Exochomus 4-pustulatus* L. These, however, are general feeders, and were seen to occur more abundantly on trees infested with *Chrysomphalus dictyospermi*, *Parlatoria zizyphus*, and *Lepidosaphes beckii* than on those infested by the black scale. *Rhizobius ventralis* Er., the most important coccinellid on the black scale in California, was not seen in Spain or Italy.

CHRYSOMPHALUS DICTYOSPERMI Morg.[1]

DISTRIBUTION AND INJURY.

Chrysomphalus dictyospermi is found in most of the citrus sections of Spain. It was commonly observed at Malaga, Seville, Murcia, and Valencia. In the Valencia section it was most injurious at Piaporto, Picaña, and Piug. At each of these places fumigation, introduced by Mr. R. S. Woglum, of this bureau, was seen in practice. Here the scale occasioned severe injury to the trees, mostly through the dropping of the leaves. While it was observed in scattering numbers around Burriana, nowhere was it seen to do any important injury. Why it does not occur there in greater numbers is not known. It was thought that parasites must be at work, but practically no evidence of parasites was seen, so far as examination was made during the month of March. That this scale was not recently introduced in the Burriana district appears to be indicated from the fact that it occurs there over such a large area. This scale was also seen occasionally around Alcira in the "Ribera."

[1] Spanish, *Piojo rojo;* Valenciana, *Poll roig;* in Murcia and provinces of Andalucia, *Cochinella rojo;* Italian, *Cocciniglia bianco-rosso;* Sicilian, *Bianca-russa.*

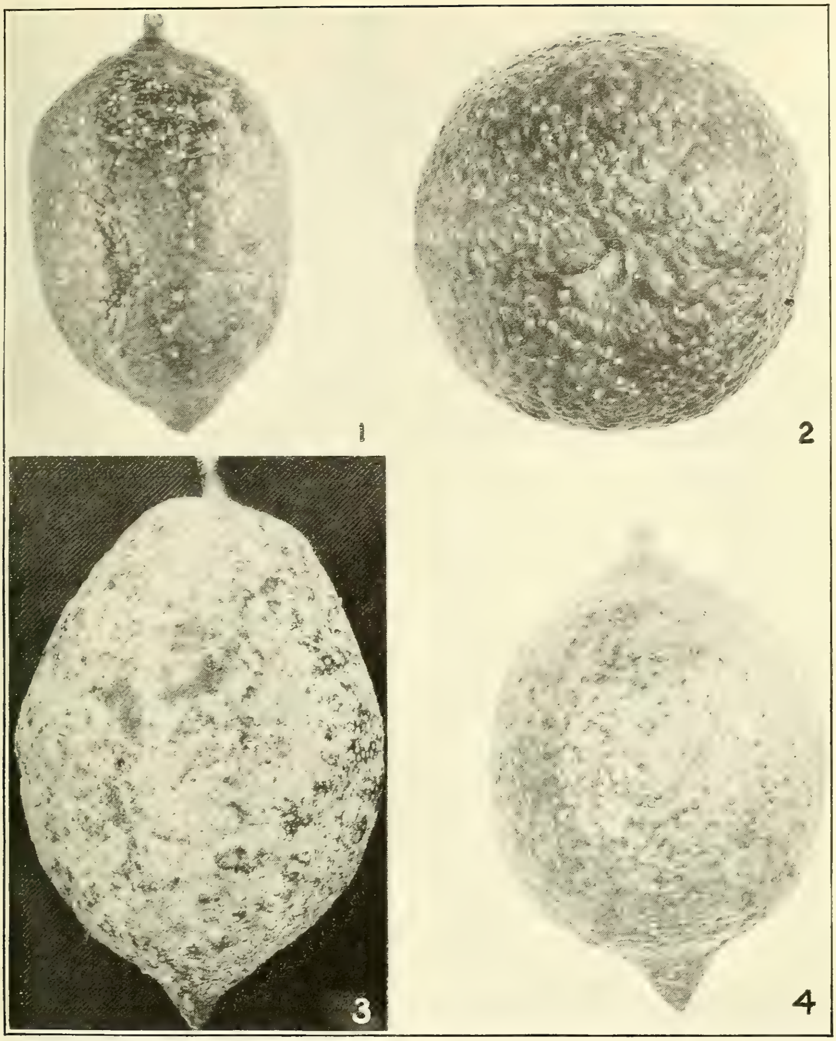
If this scale occurred widely over the Valencia section in such numbers as at Piaporto, Picaña, and Piug, it would, of course, outrank the black scale in destructiveness. At the points mentioned it is the most serious of all the scales because of its damage to the tree, as well as its effect on the market value of the fruit. It occurs also in injurious numbers farther south, as at Murcia, Malaga, and Seville. It is very commonly seen on the fruit in the markets in these sections, and the trees in many places show the effect of the scales. Even in the famous Patio de los Naranjos (Court of Oranges) of the mosque at Cordova and of the cathedral at Seville the trees are having a hard struggle to exist on account of the severe infestation by this scale. Taking the entire citrus area of Spain this scale may be the most important, but in the important commercial section of Valencia, where 90 per cent of the crop is produced, it is first only in a few small areas.

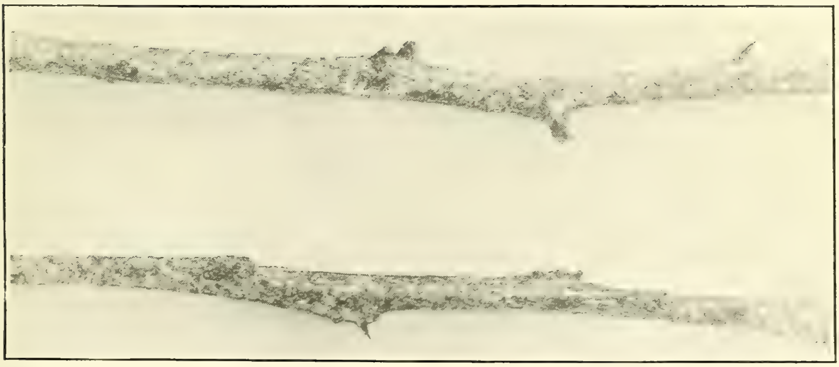
In the citrus belt along the French and Italian Riviera this species was seen at San Remo and Porto Maurizio; at the former place in destructive numbers on a few small trees. In Sicily it occurs at Catania, Messina, and Palermo. (Pl. III, fig. 4; Pl. IV, figs. 1 and 2.) At Messina it is found in several places around the city and does considerable injury. Its first recorded appearance on the island, four or five years ago, was at this place. At Catania it is more or less widely distributed, while at Palermo it is still limited to a few small areas, but it is destructive as far as its spread has occurred.

LIFE HISTORY AND HABITS.

This species, somewhat like the yellow scale (*Chrysomphalus aurantii* Mask., var. *citrinus* Coq.), attacks the leaves and fruit largely. These will be found heavily infested and often there will be but a few on the twigs and branches. This habit of avoiding the twigs and branches is not so complete as with the yellow scale, but is distinctly more pronounced than with the California red scale (*Chrysomphalus aurantii* Mask.). In severe infestations, of course, and where the leaves have fallen, *C. dictyospermi* will be found in considerable numbers on the twigs. Because the twigs and branches are not so severely infested the injury is neither so great nor so rapid as is the case with *C. aurantii*. But the dropping of the leaves greatly injures the tree temporarily and new leaves scarcely grow out until they in turn are attacked.

While the life history of this species has not been worked out in detail, it is probably very similar to that of *C. aurantii*. The latter species requires two and one-half to four months for its development. There would thus be between three and four, possibly four, full generations in a year.





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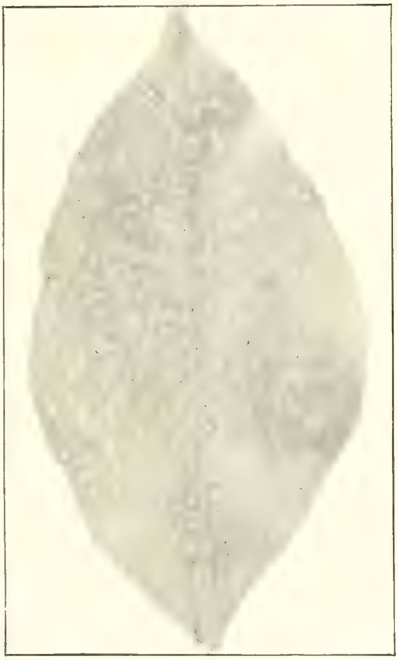
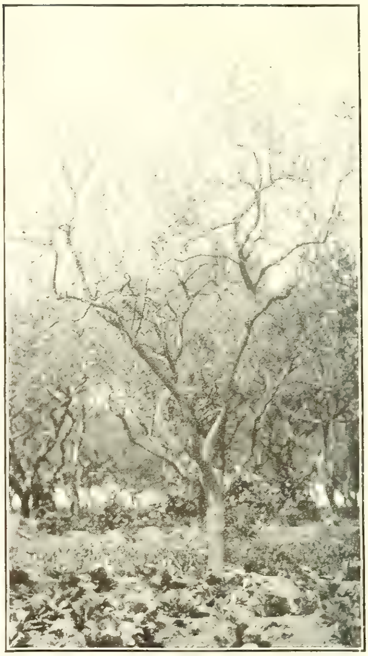
SOME SCALE INSECT ENEMIES TO CITRUS FRUITS IN SPAIN AND ITALY.

Fig. 1.—Lemon distorted by the oleander scale, *Aspidiotus hederae;* Italy. Fig. 2.—An orange infested with a common citrus scale, *Parlatoria zizyphus;* Spain. Fig. 3.—Lemon incrusted with *Aspidiotus hederae;* Sicily. Fig. 4.—Lemon infested with *Chrysomphalus dictyospermi;* Sicily. Fig. 5.—*Parlatoria zizyphus* on lemon twigs, Sicily. (Original.)



CHRYSOMPHALUS DICTYOSPERMI ON ORANGE LEAF, SICILY. (ORIGINAL.)



LEMON TREE PARTIALLY KILLED BY CHRYSOMPHALUS DICTYOSPERMI. (ORIGINAL.)

SCARS RESULTING FROM FEEDING OF THRIPS, PROBABLY HELIOTHRIPS FASCIATUS. (ORIGINAL.)

INSECT ENEMIES OF CITRUS FRUITS IN SICILY.

NATURAL ENEMIES.

The most abundant parasite of this scale is a species of Aphelinus.[1] Two or three species of Coccinellidæ have also been seen feeding on the scale. These are the same species as those already given for the black scale.

THE PURPLE SCALE.[2]

Lepidosaphes beckii Newm.

DISTRIBUTION AND INJURY.

The purple scale was seen in most of the citrus sections of Spain and Italy. It is found very generally in the Valencia orange section and in the Sicilian lemon section. Not infrequently the numbers are sufficient to do injury to the trees. This consists of the killing of a few branches, or a portion of one side of the tree. (Pl. V, fig. 1.) The scale is also more or less common on the fruit. It occurs in many places in Sicily in only scattering numbers, and in small areas, or, on a few trees, in large numbers. This is about the status of the scale in California and Florida and the Valencia section of Spain, but on the island of Sicily it is less injurious than in any of these three localities.

LIFE HISTORY.

The purple scale deposits from 40 to 80 eggs, which are well inclosed by the scale covering above and a lighter, cottony covering beneath. The eggs hatch in 15 to 20 days in summer. Most eggs and young will be found in the spring—May and June—and another large batch in August and September. At all other seasons eggs will be found, but usually in less numbers. The period of development from hatching to egg-laying ranges from one and one-half months in summer to three months in winter.

NATURAL ENEMIES.

The purple scale has been considered a pest of little economic importance in Mediterranean countries, and this has been accounted for through the efficient work of parasites. The writer takes exception to both of these counts. Just as severe injury has been seen from this scale in Spain as in California or Florida. And further, what natural enemies are keeping it in check? Hitherto, so far as known, no internal parasite has been reported from the purple scale in Sicily. Dr. Martelli was informed by the writer that he had seen evidence of *Aspidiotiphagus citrinus* attacking the purple scale, but the observation was questioned on the ground that the scale was *Lepidosaphes ulmi* and not *L. beckii.* Of course, the parasitized scales were not positively identified at the time. Later *Aspidiotiphagus citrinus*

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[1] This species appears to be *A. diaspidis*, but its identity, according to Prof. Silvestri, of Portici, is somewhat questionable.

[2] Spanish, *Serpeta;* Italian, *Pidocchio a virgola;* Sicilian, *Pidocchiu.*

Craw was reared from scales on citrus trees, and those scales from which they emerged were positively identified, as was expected, as *L. beckii*. The record, therefore, stands. Dr. Leonardi, of Portici, a specialist on the Coccidæ, stated that he had seen some evidence of a parasite on the purple scale, but he had not as yet studied it and did not know the species. When the entomologists of Italy know so little about the parasite, and when it was only very rarely found by the writer, it certainly can not be counted as very effective in checking the scale. The only other enemies of this scale seen in Sicily and Spain were coccinellid beetles, and while these are more effective than *A. citrinus*, they have not been seen in large numbers, and are not accountable for keeping the scale in check.

Places have been seen in Sicily which were very free from the purple scale, but according to the growers the scale had been present there in considerable numbers several years ago, and disappeared. Because of the meager knowledge of scales and the confusion of names by most Sicilian growers, the foregoing may or may not be true. It is, however, altogether probable. (For a discussion of climatic influences, see under Meteorological data, pp. 34–35.)

THE LONG SCALE.[1]

Lepidosaphes gloverii Pack.

DISTRIBUTION AND INJURY.

The long scale, so far as observed by the writer, is limited to Spain. In that country it is particularly destructive in some sections. It is frequently associated with the purple scale, as in the Valencia section. In some cases it was more abundant than the purple. Trees most injured by this scale were seen near Burriana. (Pl. V, fig. 1.) The long scale also occurs in Florida, from which place it was first described. It has been reported from two counties in California, though it has never spread and is of no consequence as a pest there. It is distinguished from the purple scale in being much more slender, and the pygidial differences are also distinct.

PARLATORIA ZIZYPHUS Lucas.[2]

DISTRIBUTION AND INJURY.

Parlatoria zizyphus is the commonest of all the scales occurring on the lemon tree in Sicily. (Pl. II, fig. 2; Pl. III, fig. 5.) It is also found in most of the orange sections of Spain. (Pl. III, fig. 2.) In the Valencia section it was most abundant in the "Ribera" in the vicinity of Alcira. This scale ranges in abundance from a few scattering scales to a heavy incrustation on the leaves, twigs, and fruit. It

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[1] Spanish, *Serpéta larga*.

[2] Italian common name, *Pidocchio nero;* Sicilian, *Pidocchiu niuru:* Spanish (Valenciana), *Poll négre*.

has been noted in several instances to cause a heavy dropping of the leaves, and it is one of the commonest scales occurring on the fruit in the markets. This may be partly because it adheres so firmly to the fruit and is not easily removed by rubbing. While it occurs abundantly in Sicily it is not extremely injurious to the tree, nor does it distort the fruit as does *Aspidiotus hederae*.

NATURAL ENEMIES.

This scale is especially free from parasites. On one occasion *Aspidiotiphagus citrinus* was obtained from material infested by *zizyphus*, but it can not be positively stated that there were not a few purple scales among the material, so the record remains doubtful.

THE OLEANDER SCALE.

Aspidiotus hederae Vall.[1]

DISTRIBUTION AND INJURY.

The cosmopolitan and omnivorous oleander scale is found throughout Spain and Italy and is an important pest on ripe lemons in the latter country during the spring and early summer. (Pl. III, figs. 1 and 2.) It was also observed on oranges in Spain, but is less injurious on oranges there than on lemons in Italy. In California the same scale occurs occasionally on old over-ripe oranges and lemons, but is of no commercial importance. In May and June it is really a pest of much economic importance in Italy. If such infestation occurred in California, it would certainly mean fumigation. As much as 90 per cent of the fruit in some of the by-product factories has been seen infested with this scale. Most of such fruit was brought there because of it.

The oleander scale very seriously distorts the growth of the lemon in Italy. (Pl. III, fig. 1.) Where the scale occurs there will be a depression, so that the fruit has a rough and uneven appearance and when numerous it becomes badly misshapen and distorted. The scale also delays the coloring of the lemon, and such fruit can be distinguished at a long distance by its blotches of yellow and green. While the inferior fruit caused by the scale is considerable in Italy, it is not a complete loss because it is acceptable for the by-product factory. On the Amalfi coast, where fruit of the finest texture is produced, it would seem that spraying, at a time when the young first appear, would in many cases be profitable.

NATURAL ENEMIES.

A species of Aphelinus is the commonest parasite on this scale in Italy. On host plants other than Citrus this parasite was sometimes seen in very large numbers. *Aspidiotiphagus citrinus* has also been taken from *A. hederae*.

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[1] Italian, *Bianca;* Sicilian, *Bianca o rugna.*

THE COTTONY CUSHION SCALE.

Icerya purchasi Mask.

DISTRIBUTION AND INJURY.

The cottony cushion scale was observed at Acireale, Messina, and Bagheria in Sicily. It was not seen elsewhere in Italy, except at Portici, and was not observed anywhere in Spain. It is of recent introduction in Sicily (five or six years ago) and is supposed to have come from North America or Portugal. A severe infestation occurred at the places mentioned in Sicily as observed in April. Several trees were killed and cut down at Bagheria. (Pl. V, fig. 2.) *Novius cardinalis* was seen at work at Messina and Acireale, but after persistent search none could be found at Bagheria despite the fact that the beetle had been liberated by Dr. Savastano in February. Dr. Savastano was informed of this fact, and another colony was promptly liberated. When the place was again visited in August it was gratifying to see that apparently the entire infestation was completely checked by the work of the beetle. The owner of the grove, who in May despaired of saving any of the trees, in August was elated and believed it little short of miraculous that he could be freed of the pest in such a short time. This infestation was so completely cleaned up that Novius had disappeared for lack of food, and no trace of the beetles could be found in August. These same conditions have been observed in California; the beetles, upon eating all of the scales by midsummer, would themselves disappear, reappearing, however, in the following spring. The few young scales that escaped the beetle the year previous would multiply to such an extent that a heavy infestation occurred by the following spring and would thus furnish food for the returning beetles wherever they came from. These circumstances were observed for four successive seasons in a particular grove in California, where the trees were finally cut back. It is hoped that these same circumstances will not prevail at Bagheria.

LIFE HISTORY.

From 500 to 800 eggs are deposited in the large fluted cottony mass which is secreted for this purpose. The eggs hatch in from 10 days to 3 weeks, depending upon the temperature. The young larvæ settle on the leaves and tender twigs largely, but later nearly all those on the leaves migrate to the twigs and branches, adults being found even on the tree trunk. The time required for development varies considerably under the same conditions and may range from three to four or five months. The great majority of eggs and young appear during May and June.

FIG. 1.—ORANGE TREES PARTIALLY KILLED BY THE PURPLE SCALE (LEPIDOSAPHES GLOVERI) AND THE LONG SCALE (LEPIDOSAPHES BECKII) AT BURRIANA, SPAIN. (ORIGINAL.)

FIG. 2.—LEMON TREES KILLED BY THE COTTONY CUSHION SCALE (ICERYA PURCHASI) AT BAGHERIA, SICILY. (ORIGINAL.)

SCALE INSECT ENEMIES OF CITRUS FRUITS IN THE MEDITERRANEAN.

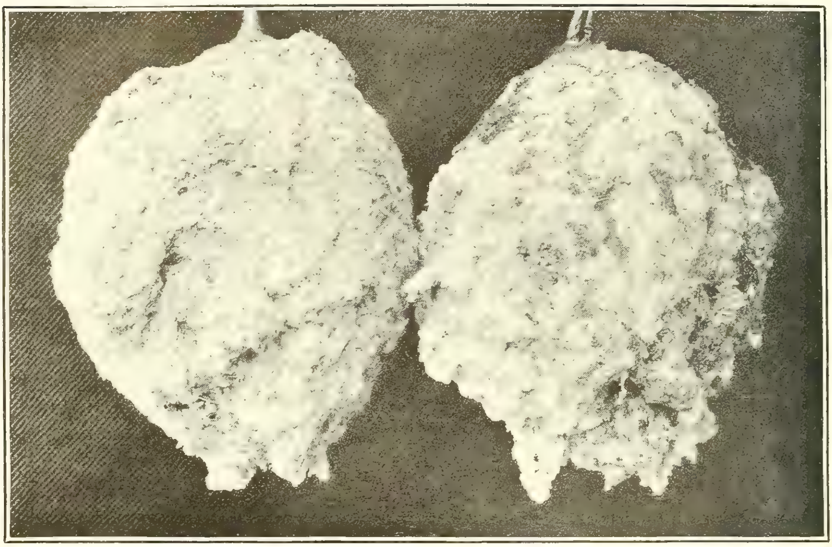

FIG. 1.—THE MEALY BUG (PSEUDOCOCCUS CITRI) ON ORANGES, SICILY. (ORIGINAL.)

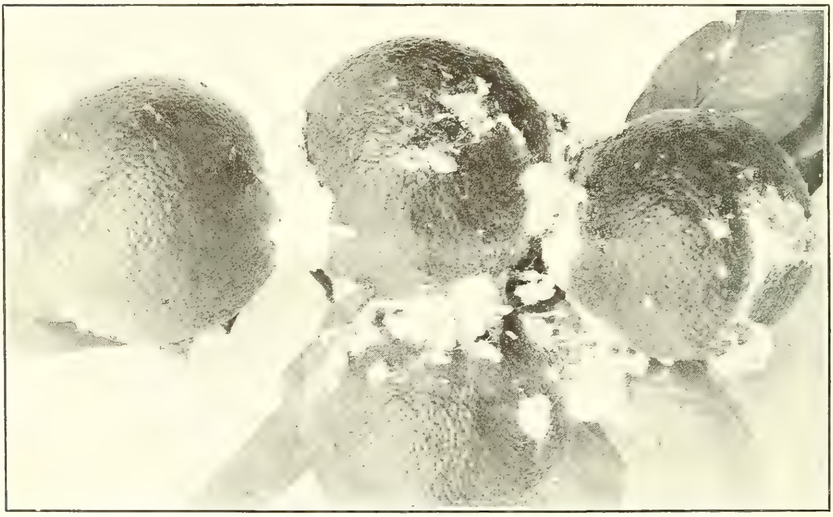

FIG. 2.—LEMONS WITH SEVERE INFESTATION OF MEALY BUG (P. CITRI), ACIREALE, SICILY. (ORIGINAL.)

DAMAGE TO CITRUS FRUITS BY THE MEALY BUG.

NATURAL ENEMIES.

The one important natural enemy of this scale in Italy, as elsewhere, is the Australian ladybird, *Novius cardinalis* Muls. This beetle, as already intimated, has been introduced into all the known colonies of the scale in Sicily. The beetle has also been distributed with success in Palestine.

Cryptochaetum icerya Will., a dipterous parasite, is the second most important enemy of the cottony cushion scale in some of the countries where it occurs, but it was not taken by the writer in Sicily. It is a small fly of a metallic green color, the larva of which lives within the scale.

THE CITRUS MEALY BUG.[1]

Pseudococcus citri Risso.

DISTRIBUTION AND INJURY.

The citrus mealy bug is found in greater or less numbers in nearly all parts of the citrus sections of Spain and Italy. It frequently occurs in serious numbers, and masses of the insects, with their cottony secretion and also much sooty-mold fungus, will be found on the leaves and fruit. In Sicily during the season of 1913 the writer unhesitatingly places the mealy bug at the head of all the citrus insect pests. *Chrysomphalus dictyospermi* is serious enough in several places, but the area involved is small as compared with that seriously infested with the mealy bug. The scale is also more amenable to treatment. The worst infestations of the mealy bug occurred along the east coast at Catania, Acireale, and Messina, and several intermediate points, though bad infestations were also seen at several points on the north coast. In many places the numbers were so great that the masses of cotton extended for an inch or two below the fruit. (Pl. VI, figs. 1 and 2.) Many of the lemons fell from the trees, others were stunted in growth, and a heavy dropping of the leaves occurred. The fallen fruit and leaves, with the insects and cotton still on them, gave the ground a distinctly whitish appearance.

Infestations of the mealy bug in Sicily in 1913 were just as severe and much more extensive than were those in the Ventura and San Diego sections in California a few years ago. Even outside of these extremely severe infestations, the insect was generally distributed and much more abundant throughout the entire citrus area in Sicily than was ever seen in California outside of the two sections mentioned.[2]

[1] Spanish (Valenciana), *Cotonet;* Italian, *Cocciniglia farinosa degli agrumi;* Sicilian, *Cuttunedda.*

[2] The writer may be pardoned for making frequent comparisons between the Mediterranean citrus sections and that of California, but this is done for three reasons: First, people can best judge of conditions in foreign countries in terms of their own conditions; second, California is most like the Mediterranean citrus region; third, the writer is acquainted with citrus conditions in California.

It was stated by many people that the mealy bug was unusually abundant on the island in 1913.

LIFE HISTORY.

The mealy bug lays 300 or 400 eggs in the cottony mass that is secreted for the purpose, and these hatch in from 10 days to three weeks, according to the season. The development ranges from one month in summer to three in winter.

NATURAL ENEMIES.

The natural enemies of *P. citri* in Sicily are varied and numerous. The writer has found feeding on or attacking this insect one species of Hemiptera, two of Neuroptera, two of Coleoptera, two of Diptera, and six or seven of Hymenoptera. Of these, probably the most important is one of the species of Diptera. Two or three species of Hymenoptera were also very common, as well as one of the coccinellids.[1]

In spite of all these enemies the mealy bug was the worst citrus pest in Sicily in 1913. The increase and decrease of this insect there, however, may be very greatly influenced by the attacks of all these enemies.

PRAYS CITRI Millier.[2]

DISTRIBUTION AND INJURY.

Prays citri is the name of a small moth the larva of which often does serious injury to the blossoms of the orange and lemon. It is found in Sicily, in the Provinces of Calabria and Campania, and probably in other less important citrus sections of Italy. It was seen to be particularly abundant in the vicinity of Messina in August, 1913, and a large percentage of the blossoms and newly formed fruit was destroyed. It occurs from April to November, but is especially destructive to the blossoms of the forced *verdelli* crop, which occurs in midsummer. The injury is caused by the larvæ eating into all the flower organs—stamens, pistils, petals, and ovule.

LIFE HISTORY.

The eggs are deposited apparently upon the calices or peduncle of the flower, usually just prior to opening. The larvæ upon hatching bore through the inclosing parts to the organs within. Flowers thus attacked will have holes in the calyx, parts eaten out of the stamen, or burrows made into the pistil and ovule. Pupation usually occurs within the flower, but also in protected places on the leaves or forks of the twigs and branches.

[1] These different species of parasitic and predaceous enemies of the mealy bug in Sicily may be treated in more detail in a later paper.

[2] Italian common name, *Tignola degli agrumi.*

RED SPIDERS.

One species of red spider was seen in all the citrus sections of Spain and Italy. With a few exceptions, however, the numbers were not sufficient to do any great injury. Over small areas, particularly along the roadside where there was considerable dust on the trees, many of the leaves had the characteristic light-colored mitelike areas. Not infrequently, too, the lemons would be scarred around the depression formed by the nipple at the calyx end, this situation being the most favorable feeding place on the fruit.

This species is identified by the Italian entomologists as *Tetranychus telarius*. What we have been calling *telarius* in this country has recently been made synonymous with *T. bimaculatus* Harv. The habits of *bimaculatus* in the citrus belt of California are very different from those of *telarius* in Spain and Italy. *Bimaculatus* has been observed to infest severely other food plants growing in the midst of citrus trees, both in California and Florida, without attacking the citrus trees at all. *Bimaculatus* on beans, violets, and a long list of other plants, feeds generally over the entire surface. *Telarius* in Spain and Italy feeds in restricted areas precisely as does *T. sexmaculatus* Riley on citrus trees. But red forms of *telarius* are common in Mediterranean countries, while in California all that have been observed of *sexmaculatus* are pale colored. The writer is not, however, necessarily assuming that *sexmaculatus* and *telarius* are synonyms, though their feeding habits are similar. He is, however, of the opinion that, judging from their difference in feeding habits, our *bimaculatus* and the European *telarius* are not synonymous if the Mediterranean citrus species is properly identified as *telarius*.

Another species which is flat and scalelike, probably a species of Tenuipalpus, was occasionally met with on citrus foliage in Sicily.

THRIPS.

A species of thrips, said to be *Heliothrips fasciatus* Perg., occasionally does some injury to the orange as shown by the marred fruit. (Pl. IV, fig. 3.) But thrips scars on the fruit in Spain and Italy are rare, so that the insect is of little economic importance. Around Jaffa, however, a species of thrips sometimes does considerable injury, and spraying has been necessary.

THE CONTROL OF CITRUS FRUIT INSECTS IN MEDITERRANEAN COUNTRIES.

With the exception of a little fumigation in Spain for the control of *Chrysomphalus dictyospermi*, and limited spraying in Sicily for the same insect, practically no remedial measures are employed for the control of citrus fruit insects in the countries bordering on the Mediterranean. This fact might be taken to mean that the pests there are of little economic importance because of their natural enemies, or for some other reason. But the lack of preventive measures in those countries as compared with California and Florida is largely a question of standards.

The black scale is as serious a pest in Spain as it is in California. A large share of the million dollars a year spent in California for the control of citrus pests is counted against this insect. The black scale is not, however, as serious a pest in Sicily as it is in California and Spain. The purple scale injures trees and mars fruit in Spain and Italy as it does in California and Florida. The long scale is more injurious in Spain than it is in Florida, so far as the writer's observations have extended in Florida. This scale is not reported from Italy. While it is recorded from one or two small sections in California, it is of no consequence as a pest. *Parlatoria zizyphus* not infrequently causes a heavy dropping of the leaves, and also attacks the fruit both in Spain and Italy. It is not a general pest in the groves of California or Florida. It is often taken, however, on lemons in the markets of the eastern States, having been imported from Italy. *Aspidiotus hederae* is a more serious pest on ripe lemons in Italy than it is anywhere in the United States. The mealy bug, *Pseudococcus citri*, ranks just as high, if not higher, as a pest in Spain and Sicily than it does in California. The citrus white-fly, the most serious of the Florida citrus pests, does not occur in the Mediterranean region.

Nothing in the way of artificial control is practiced against any of the foregoing insects in any of the Mediterranean countries. One or two cases were met with in Spain where the grower had tried some patent concoctions on a few trees. Pruning, however, may come in the category of control for insects in those countries more than it does with us, as the following dialogue may illustrate: "What do you do for the scales when they actually kill the twigs and branches as seen on the trees before us?" "We cut out the twigs and branches." Cutting out dead twigs and branches is, of course, a part of the pruning process, and not infrequently these dead parts are due to one of the foregoing insects. If the fruit is infested with the sooty-mold fungus, it is washed in sawdust, but the cause is not taken into consideration. If scales are present on the fruit, such fruit is placed in an inferior grade, or it is consigned to the by-product factory.

In the case of *Chrysomphalus dictyospermi*, however, a start in control work is really being made both in Spain and in Italy. This is no doubt due to the fact that this scale causes more complete injury to the trees—indeed, practically kills them. As before stated, fumigation was seen practiced in Spain last year at Piaporto, Picaña, and Piug in the Valencia section. Possibly it is practiced also in other places, but evidence was not seen elsewhere at the time of the writer's visit. Mr. R. S. Woglum, of this bureau, introduced fumigation in Spain in 1910, and it is being carried on in accordance with modern California methods. (Pl. X, fig. 4.) The cost as figured from a definite number of trees amounted to 1.10 pesetas, or about 20 cents per tree. In actual practice growers state that the cost averages from 25 to 30 cents a tree, which is about the same as that of California for trees of the same size. There are no large trees in the Valencia section and there are no seedlings.

Advocated by Dr. L. Savastano,[1] the well-known pathologist, director of the experiment station at Acireale, the use of lime-sulphur is becoming popular for the control of *C. dictyospermi* in Sicily. Fumigation is out of the question in most parts of Italy where citrus trees are planted solidly because of the nearness of the trees. Spraying, therefore, is the only artificial measure that may be employed. The lime-sulphur spray is intended to kill the young largely. It is applied in June and again in August or the first part of September. The strength used is 5 per cent of lime-sulphur of 1.25 gravity (29° Baumé). This is for summer use when high temperatures may cause burning if used stronger. During the winter it is used at a strength of 8 per cent and, if the infestation is severe and many of the leaves off, as high as 10 per cent. Lime-sulphur at the strength mentioned will probably kill most of the young that are hit, and if the application is repeated two or three times the numbers of the pest will be considerably lessened. Two or three sprayings are recommended at first to clean the trees, and then only one spraying annually thereafter. The same spray is recommended by Dr. Savastano with good results against *Aspidiotus hederae* and *Lepidosaphes beckii.*

The spray as used in the groves of Sicily is applied by means of a hand pump mounted on a wheelbarrow truck. This is about as large an outfit as may be used under the trees. No horses ever enter most of the Italian citrus groves, all the work of cultivation, etc., being done by hand labor. From the writer's observations a very great improvement resulted from the applications of lime-sulphur. Not all the insects were, of course, killed, but the numbers were greatly lessened, and a marked improvement in the trees resulted. This spray has the advantage, also, of checking many of the possible fungous troubles as well as stimulating the growth of the tree.

Aside from the control measures mentioned, Dr. G. Brigante[2] states that the worm, *Prays citri*, of the blossoms may, if necessary, be handled by a 1 per cent solution of lead arsenate. But poison sprays are in bad repute in Italy.[3] Prof. Ampola and Dr.

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[1] Savastano, L. Le conclusioni pratiche per la poltiglia solfocalcica (formo a della Stazione). R. Staz. Sper. di Agr. e fruitti coltura, Acireale, Sicily. Bol. no. 11, 11 p., April, 1913.

[2] La coltivazione degli agrumi in Provincia di Salerno, Dott. G. Brigante, Direttore Cattedra Ambulante di Agricoltura per la Provincia di Salerno, 1912.

[3] Insetti damnosi e composti arsenicali, Teodosio De Stefani, Gazetta Commerciale, Palermo, p. 5–10, 1912.

Tomasi, of the Station Chimico-Agraria Sperimentale di Roma, strongly recommended the prohibition of arsenicals for general agricultural purposes. They conclude that their use is injurious to all sorts of plants and animals, but the most potent of their reasons is that the farmers, instead of poisoning their insect foes, might destroy human life. In addition to these control measures practiced in Spain and Italy, a small amount of spraying has been done around Jaffa in Palestine for a species of thrips on the orange. From the little evidence of thrips work that was seen at Jaffa the species occurring there is not *Euthrips citri*, as was supposed.

MEDITERRANEAN CITRUS FRUIT INSECTS THAT DO NOT OCCUR IN THE UNITED STATES AND THE POSSIBILITY OF THEIR INTRODUCTION.

Of the citrus insects discussed in the foregoing pages, two do not occur in the United States, namely, *Ceratitis capitata* and *Prays citri*. Two others, *Chrysomphalus dictyospermi* and *Parlatoria zizyphus*, while occurring in the United States, do not appear to be established as important pests, as is the case in the Mediterranean region. Concerning the distribution of these two scales, Mr. C. L. Marlatt, under date of March 5, 1914, writes as follows:

> *Chrysomphalus dictyospermi* is frequently found on palms and quite a number of other plants which are probably imported, and has a wide distribution in greenhouses. Out of doors it does not seem to thrive very well on this continent, and I think we have very few outdoor records of it, and these naturally from southern points. It has been so often brought into this country that its failure to establish a foothold in citrus orchards apparently indicates unfavorable conditions for this insect, but it is, of course, possible that this may have resulted, after all, from lack of favorable opportunity. *Parlatoria zizyphus*, as you know, is brought to this country all the time on Italian lemons, and has been found in the open market wherever these lemons are sold, including well-established citrus districts such as those of Florida and Louisiana.

In case these two scales did become established in our citrus groves our present control methods, at least fumigation, would handle them successfully. This fact, however, should be no excuse for not quarantining against them. On the other hand, the other two, *Ceratitis capitata* and *Prays citri*, would not only be serious pests but would not be controlled by any of our methods now in use for citrus trees. Ceratitis, moreover, is not limited as a pest to citrus fruits; indeed, citrus fruits are by no means its favorite food, but it attacks a long list of deciduous fruits. The scope of this paper has to do, however, chiefly with citrus fruits.

The first shipments of oranges are made from Spain as early as October, and a few of the mature fruits at this time may contain larvæ of Ceratitis. But with the approach of cold weather in November and December the fly disappears. The time when infested fruits might be received from Spain is at the beginning of the shipping season in October and November, and again during the final shipments, the last of June and first of July. The reason more infested oranges do not occur in Spain is not, as has been suggested, because the fruit is picked too green, but because practically all the fruit matures and is harvested at a season when the fly is not active or breeding. This applies to practically all semitropical countries where citrus fruits are grown commercially. Plenty of oranges were seen in Spain that were fully mature in March, but which were not harvested until May or June. The heavy shipments do not begin in Spain until November, and by May the season is virtually ended.

What has been said regarding oranges in Spain applies to all the Mediterranean citrus sections. Up to the middle of October in Palestine the oranges were still too green to be infested with Ceratitis. Even though the fly may be present and actually deposit eggs in the fruit, there is no danger of the larvæ developing if the fruit is immature. In spite of numerous punctures and eggs in the fruit which were seen in Sicily up to October 1 and in Palestine up to October 15, no larvæ succeeded in developing or getting beyond the egg cavity, but there perished.

The lemon is an unusual and rare host for Ceratitis, at least in the great lemon-producing section of Sicily. It was only very rarely, and, it must be admitted, more or less accidentally, and after much persistent searching, that lemons were found infested in Sicily. Out of numbers running into hundreds of thousands only 15 were found infested. And all of these infested lemons were so badly broken down by decay that they would not only be rejected for shipping, but, with three or four exceptions, would be rejected for the by-product factory. So far as one season's experience in Sicily warrants the conclusion, therefore, there is only the remotest possibility of the entrance of Ceratitis into this country through the importation of lemons from Italy.

In the case of most other fresh mature fruits, which are harvested between May and November, inclusive, and coming from the Mediterranean countries, the possibility of Ceratitis introduction can be removed only through a strict embargo against such fruits or a subjection to a rigid inspection.

THE OLIVE FLY.

Dacus oleae Rossi.

Since the olive is usually grown in the same countries as citrus trees, it may be pertinent in this place to mention the olive fly. This insect, *Dacus oleae*, is one of the most serious pests of the Mediterranean countries. In fact it is the opinion of the writer that it far outranks *Ceratitis capitata*. A heavy infestation of the olive fly has been seen in different places, but particularly in Sicily and southern

Italy. Most of the olives attacked fall to the ground before reaching maturity. In the case of the olive fly, mature fruit is not at all necessary for infestation. Because of the economical use made of all the inferior fruit in these countries—something we have yet to practice—infested olives are not a complete loss, for they are used for oil, most of which is used in the manufacture of soap. The striking difference in habits between the olive fly and the Mediterranean fruit-fly is that, with the former, pupation occurs within the fruit, instead of in the ground or otherwise out of the fruit as is the case with Ceratitis.

Infested olives may be distinguished by a circular area on the surface that is of a light gray color. Before entering the pupal stage the larva eats out a channel to the surface of the fruit, leaving only the thin epidermis. It is this, with the tissue eaten away below, that forms the characteristic gray area that indicates infestation. It is much the same as that made in the case of the pea and bean weevils. Having completed the burrow to the surface, the larva retreats a short distance and transforms to the pupa, enclosed in the characteristic puparium, that looks much like that of Ceratitis. Upon emerging the adult fly breaks through the epidermis, which has been left for protection, by means of its ptilinum.

Fortunately olives are not transported unless pickled, and thus the danger of introduction is not great. But a sharp lookout should be kept for any olives that might possibly be imported fresh from these countries, since the egg, larval, and pupal stages are all passed within the fruit.

THE MEDITERRANEAN CITRUS FRUIT INDUSTRY.[1]

SPAIN.

LOCATION.

The most important citrus section of Spain, where 90 per cent of the crop is produced, consists of a narrow strip, 10 or 15 miles wide and 150 miles long, extending from Denia in the Province of Alicante northward as far as Vinaroz in the Province of Castellon. This is the so-called "Valencia section," the city of Valencia being situated somewhere near the center of the strip. In this section are recognized two distinct districts, the "Ribera" and the "Plana." The "Ribera" lies to the south of Valencia and centers chiefly about the towns of Alcira and Carcagente. This district is more or less rolling and hilly and is separated from the sea, which is 15 or 20 miles distant, by hills and mountains. The "Plana" lies north of the City of Valencia and centers about the town of Burriana. This is a perfectly flat plain and borders directly on the sea. Around the

[1] In this account of the Mediterranean citrus industry only such phases are presented as are necessary to a better knowledge of the insects discussed in the earlier pages of this paper.

FIG. 1.—INTERIOR OF PACKING HOUSE AT ALCIRA, SPAIN. (ORIGINAL.)

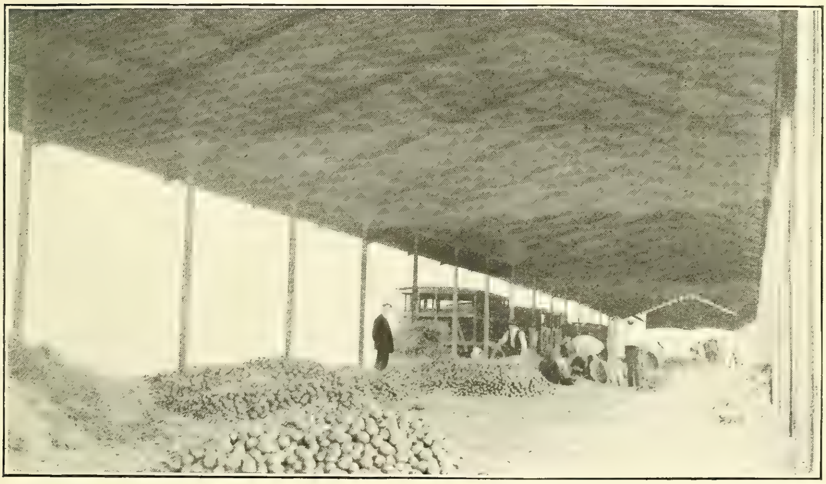

FIG. 2.—THE RAILROAD PACKING HOUSE AT CARCAGENTE, SPAIN. (ORIGINAL.)

SORTING AND SHIPPING CITRUS FRUITS IN SPAIN.

FIG. 1.—HAULING ORANGES TO THE BOAT LANDING AT BURRIANA, SPAIN. (ORIGINAL.)

FIG. 2.—LOADING ORANGES IN SMALL BOATS TO BE TRANSPORTED TO STEAMER, BURRIANA, SPAIN. (ORIGINAL.)

ORANGES IN TRANSIT IN SPAIN.

city of Valencia itself in the "Heurte de Valencia" there are few oranges grown, excepting at Piaporto and Picaña and to the westward of these villages.

Going farther southward the next important orange section is at Murcia, and then at Malaga, with a few scattering groves between. In the Malaga section probably the most important center is at Alora, some distance back from the sea, and in a mountainous country. The next important section of Andalusian Spain is in the vicinity of Seville. Here, however, practically all of the crop is of the bitter variety and is shipped to Great Britain and made into marmalade.

METHODS OF HANDLING CROP.

The harvesting season in Spain extends from October to July, with the heaviest shipments occurring from November 15 to December 1. The oranges are picked in small baskets and from these are dumped into larger baskets along the roadside or edge of the grove, thence being carried, by means of carts, to the packing house. They are here spread on the floor to a depth of about 2 feet, the floor and sides for a couple of feet being first covered with a layer of rice straw. Women sit around the edge of these piles of fruit which, if infested with sooty-mold fungus, is rubbed first in wet and then in dry sawdust to remove the mold. Other women then sort out the fruit in three different sizes, entirely by sight, and also discard the culls. The fruit is then wrapped in paper by other women and packed in the boxes.

The three sizes of fruit are represented by the cases containing respectively 420, 714, and 1,064, and which weigh 165 pounds each, or about twice that of the American box. There is absolutely no machinery in a Spanish packing house, all the processes of handling, grading, washing, and box making being done by hand. The packing house itself is, therefore, simple, consisting of four walls and a roof, the earth forming the floor. (Pl. VII, fig. 1.) The appurtenances consist of the shipping cases, a good supply of shallow wicker baskets, and plenty of women to do the work. The time the fruit remains in the packing house depends largely on the departure of the steamer and varies from a day or two to more than a week.

After the fruit is packed in cases it is hauled, in carts, without springs, to the boat landing. Here the cases are unloaded along the shore and later placed in small boats and finally transferred to the steamer. At Burriana, the port of the "Plana" district, from which 2,000,000 cases are shipped annually, there is no pier, and the small boats are pulled up on the gravelly beach by oxen. (Pl. VIII, fig. 2.) The town, which is about 2 miles inland, and in which there are upwards of 100 packing houses, is not connected with the beach by any railroad, and all of the 2,000,000 cases are hauled in carts each year, over a very bad road. (Pl. VIII, fig. 1.)

The foregoing description applies to the fruit sent by sea. A very small amount of the crop that is sent by railroad is also packed in boxes and handled in the way described. But nearly all of the fruit shipped by railroad is simply conveyed in loose carload lots. From 10,000 to 15,000 tons are exported from the Valencia district in this manner, while 400,000 to 450,000 tons are shipped by sea. Where the fruit is to be shipped by railroad in loose carload lots, the packing house occurs alongside the railroad. These packing houses are even simpler than those already described, for they consist simply of a roof, the sides being left open. The earth is graded up to the height of the floor of the car to facilitate the transfer of the fruit. The floor of this open-air packing house is covered with rice straw, as are also the floor and sides of the car. The cars are usually of the pattern of our stock cars, with lattice work on the sides to allow for plenty of ventilation. (Pl. VII, fig. 2.)

The oranges are brought from the field directly to the railroad packing house, where they are piled on the floor. Women here give the fruit the sawdust treatment, if needed, and the culls are discarded. It is now ready for the car, where it is carried in baskets and filled to the depth of a couple of feet. Such fruit goes mostly into France, or to other parts of Spain.

PRODUCTION AND EXPORT.

From figures kindly furnished by Mr. Claude I. Dawson, American consul at Valencia, the total production of oranges for the season 1912–13 amounted to nearly 7,000,000 cases of 165 pounds each. This amounts to about 38,500 California carloads or 45,117 Florida carloads. Of this amount 5,573,627 cases were shipped by sea, as follows:

	Cases.
Great Britain	2,253,076
Germany	1,374,829
Holland	501,645
Norway and Sweden	84,374
Austria-Hungary	18,110
Denmark	17,103
France	6,033
Russia	1,000

The overland shipments to France approximated 1,200,000 cases, and the remainder of the crop was consumed in Spain.

According to the figures of the United States Bureau of Statistics there were shipped into the United States from Spain in 1912, 9,000 pounds of oranges and lemons (not separately listed), valued at $204. The only records the writer was able to obtain in Spain of orange shipments to the United States were of a few small shipments during the last two or three years from Seville. The use made of these shipments was not known, but was no doubt for the manufacture of marmalade, as is the case with all the bitter orange product of Seville. One hundred and fifty thousand cases are exported annually from Seville, mostly of the sour or bitter orange, and practically all are sent to Great Britain for the manufacture of marmalade.

ITALY.

LOCATION.

The important citrus fruit areas of Italy are on the Island of Sicily, in the Provinces of Calabria and Campania, and along the Riviera di Ponente and the Riviera Levante.

The most extensive section, particularly for lemons, is in Sicily. The area extends along practically the entire north and east coasts. There are, of course, breaks in this strip, as where the mountains extend abruptly to the sea, or where grapes largely occupy the territory, as at Milazzo, Carruba, and Riposta, or on the plain south of Catania, where various other crops are grown. The limits of this area are the Gulf of Castellammare on the north and Avola, below Syracuse, on the east coast. Even within these limits lemons do not occur solidly because of the irregularity of the land, lack of water, and unsuitable soil. Most of the lemons are grown in close proximity to the coast, but occasionally they extend inward for several miles, as at Monreale, Alcantara, and Floridia. Occasionally citrus trees will be found in the interior valleys, but here it is largely oranges, probably because of the greater likelihood of frost.

In the Province of Calabria there is a considerable area of citrus fruit along the coast from Reggio to Rosarno and farther northward and inland at Cantanzaro and Cosenza. The Campania section is situated principally along the coast from Salerno through Majori and Amalfi to Positano. Here the trees are grown on terraces (Pl. IX, fig. 1), formed on the very abrupt slopes extending upward from the sea. Unlike other sections, also, the trees are covered with trellis, on which, during the winter for protection against frost and wind, is placed straw and brush. The Riviera section consists of a narrow and much broken strip extending from Ventimiglia on the French border to Spezia.

METHODS OF HANDLING CROP.

Lemons in Sicily are harvested practically every month in the year, the heaviest shipments occurring in the spring and early summer, while the fewest shipments occur during the month of August. The number of pickings in any particular grove is from four to six. The lemons are broken from the tree by hand, leaving two or three inches of stems with the fruit. These are placed in small baskets, supported in the tree or carried on the arm, and when filled are carried to the men who clip off the extra stem, leaving the usual button. In the case of *verdellis*, green lemons, during the summer, these are sometimes broken from the tree by means of a forked bamboo rod. This rod is long enough to reach to all parts of the tree from the ground, and the fruit is simply allowed to fall as it is twisted off. When asked about the effects of bruising by such a method, it was stated that the fall does not hurt the green fruit. Such a method is rapid, since the lemons are quickly twisted off and allowed to fall, and are picked up, usually by small boys, but it is not practiced by the best growers.

The fruit with the small buttons is placed in baskets and carried thus to the field packing house (Pl. X, fig. 3). Here it is roughly graded, and the culls are separated for consignment to the by-product factory. It is placed in the regular shipping boxes (Pl. X, figs. 1, 2), but thrown in loosely, with paper around the inside of the box. Sometimes with the better grades, and in the case of long hauls, each lemon is wrapped separately. In these shipping boxes the fruit is carried in carts to the town or exporter's packing house, where it is regraded, sorted, and packed back in the same boxes, when it is carried in carts to the lighter, and thence to the steamer for final shipment. (Pl. IX, fig. 2.)

The time the fruit remains in the field packing house may vary from 1 to 3 or 4 days, or longer; in the exporters' packing houses, from a day or two to a week or two. The average time of transit from Palermo to New York is 12 or 15 days. The time between the picking and the landing of the fruit in New York may thus range from 18 days to 30 or 40 days.

A large percentage of the fruit that is harvested during the spring and early summer is what is called in California tree-ripe fruit, while that harvested in midsummer and fall is mostly green fruit, or *verdellis*. *Verdellis*, of course, occur with the yellow fruit, and they are packed separately and so consigned. The large proportion of *verdellis* which occur in midsummer are artifically produced. During the previous summer water was withheld from the trees for about six weeks, and then two or three irrigations were applied in quick succession. This procedure causes the trees to throw out an unusual amount of blossoms which mature into fruit the following summer. This fact of a very large preponderance of green fruit during the summer and fall has an important practical bearing in connection with the possible infestation of the Mediterranean fruit-fly. It is during the summer and fall that the fly is most actively breeding. Very little yellow fruit appears before November, but from that time until the following July it is nearly all yellow fruit. No place was seen in Sicily where lemons are subjected to forced curing, as they are in California.

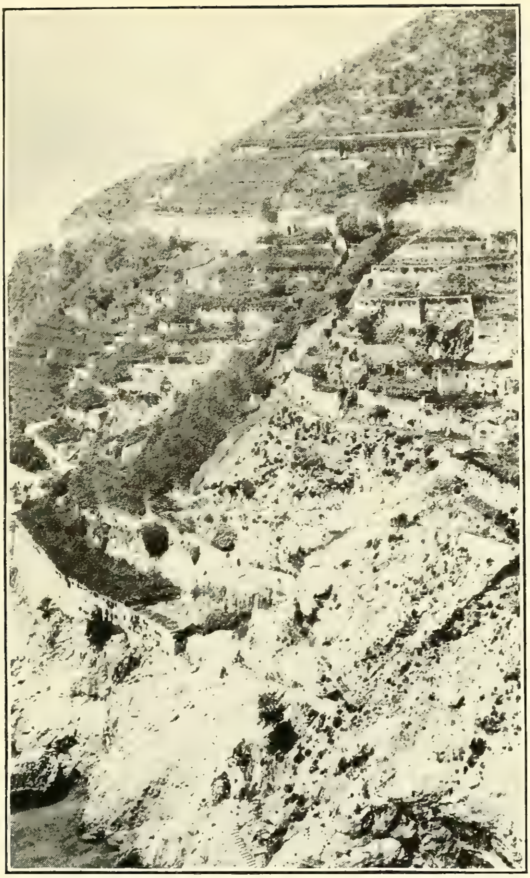

FIG. 1.—THE FAMOUS TERRACED LEMON GROVES ON THE AMALFI COAST OF ITALY. (ORIGINAL.)

FIG. 2.—LIGHTERS OF THE FELLUCA TYPE CARRYING LEMONS TO THE STEAMER, PALERMO.

LEMONS IN ITALY.

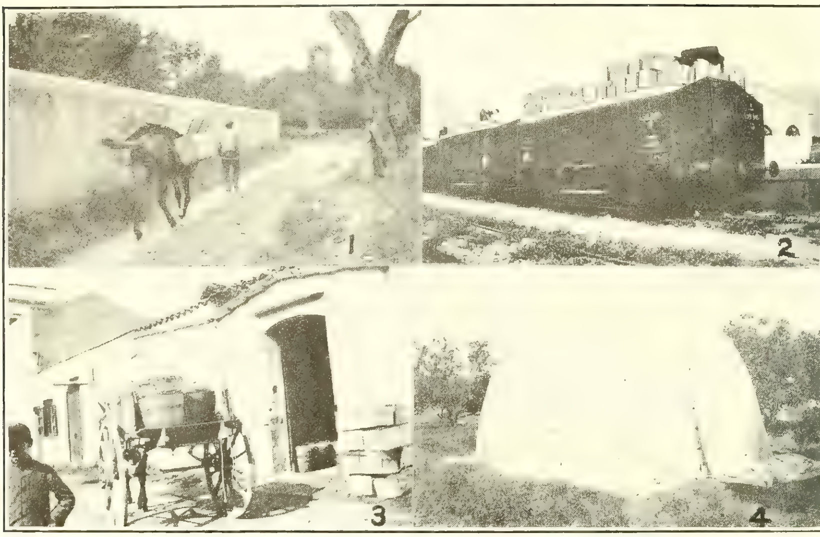

FIG. 1.—TRANSPORTING LEMONS IN THE HILLY SECTION OF SICILY, WHERE THE ROADS ARE POOR. (ORIGINAL.)
FIG. 2.—OPEN CARS (NO ROOFS) LOADED WITH BOXED LEMONS FOR TRANSPORTATION FROM THE SMALLER TOWNS TO THE SEAPORT, SICILY. (ORIGINAL.)
FIG. 3.—A "FIELD" PACKING HOUSE AND CART WITH BASKETS OF LEMONS FROM THE NEAR-BY GROVES, SICILY. (ORIGINAL.)
FIG. 4.—A FUMIGATING TENT, IN POSITION, SPAIN. MODELED AFTER THE OUTFITS ORIGINATING IN CALIFORNIA. (ORIGINAL.)

FIG. 5.—A LABORATORY AT PALERMO; THESE ARE THE PEPPER TREES. (ORIGINAL.)

TRANSPORTING LEMONS IN SICILY. FUMIGATION OF CITRUS TREES IN SPAIN.

PRODUCTION AND EXPORT.

The total acreage exclusively in citrus fruits in Italy in 1909, according to Powell,[1] was 108,400 acres, and 170,000 acres on which other crops were grown. A total of 85,252 acres were grown in Sicily, out of which 4,102 acres were in mixed cultivation; 13,890 acres entirely in citrus fruits were in the Province of Calabria and 9,385 acres in the Province of Campania.

The total production of lemons in Italy, including that converted into by-products and that used in home consumption, in 1911 was 1,192,701,829 pounds, or 47,785 of our carloads, basing this calculation on the size of the California box of lemons, which is estimated to weigh 80 pounds, and on the number of these boxes, namely, 312, loaded in the California cars. The exports of lemons alone were 570,306,431 pounds, or 22,841 of our carloads. The United States during the past 10 years has received about 35 per cent of the total exports. In 1910 the distribution among the principal countries was as follows:

	Per cent.
United States	31. 5
Austria Hungary	19. 8
United Kingdom	19. 5
Germany	11. 3
Russia	8

In 1911, 96 per cent of our Italian lemons came from Sicily, of which 86.4 per cent were from Palermo, 9.8 per cent from Messina, and 3.8 per cent from Naples, including the Amalfi Coast district. The Italian box contains about 73 pounds of fruit, which is chiefly in 300 and 360 per box sizes. About half of the total imports arrive here in May, June, and July; 85 to 90 per cent are received in New York, about 5 per cent in Boston, and smaller quantities in New Orleans, Philadelphia, Baltimore, and a few other places.

According to the United States Bureau of Statistics, the total imports of lemons from Italy in 1912 were 145,275,122 pounds, valued at $3,359,115; of oranges, 401,161 pounds, valued at $9,319.

FRANCE AND ALGERIA.

No extended observations were made in the citrus sections of France and Algeria. In France the area appears to be limited to a short and much broken strip along the Mediterranean Coast, the French Riviera, extending from Cannes to Menton on the Italian border. In northern Africa the most extensive production of oranges is in Algeria. But the output there is not large, for Algeria and France together do not produce nearly enough for home consumption in France, as evidenced by the large imports from Spain.

[1] The figures here given are from Powell, Harold C., and Wallschlaeger, F. O. The Italian lemon industry. *In* Citrus protective league of California, Bul. 10, 58 p., Jan., 1913.

PALESTINE AND EGYPT.

In the eastern Mediterranean countries the most important citrus-producing sections are in Palestine and Syria. The largest and most important district is in the neighborhood of Jaffa, the home of the well-known Jaffa orange; 1,600,000 boxes (same size as ours) were shipped from Jaffa alone last year. Most of these were sent to the Liverpool market, with smaller amounts, and of poorer grade, to Turkey, Egypt, and other near-by countries. In all the earlier plantings around Jaffa the trees are very close together—9 to 12 feet. In the later plantings, however, and particularly in the Jewish colonies, where all the best groves are located, they are from 14 to 18 feet apart. Irrigation is by the basin system, and the source is from wells, from which the water is pumped, in the Jewish colonies, by gasoline engines. On account of the sandy soil largely, water is applied every 8 or 10 days. The methods of packing and shipping are much the same as in Italy and Spain. Mr. A. Bril, a prominent grower and manager of the Jewish colonies around Jaffa, who visited the United States last year, has adopted California methods, and the fruit so handled and packed brought 25 cents a box more than other fruit.

Aside from Jaffa there is another small section around Acre, farther to the north and also along the Palestine coast. Still farther north in Syria there are citrus sections at Saida and Tripoli, there being a considerable lemon acreage in the latter place.

In Egypt citrus culture is limited to scattering groves, most of which are poorly cared for, and from which the production is limited to local consumption.

METEOROLOGICAL DATA FOR VALENCIA, SPAIN, AND PALERMO, ITALY.

Since meteorological conditions may have a very great influence on many insects, as has been specifically pointed out in the case of the black scale, the following data are given for the most important orange and lemon centers, respectively, of the Mediterranean countries.

It will be noted from the following tables that, excepting 1910, higher temperatures prevailed at Palermo than at Valencia. High temperatures at Palermo, moreover, are accompanied by extreme dryness, and usually much wind. This combination of heat and very great evaporation is sufficient to account for the scarcity of the black scale in Sicily, as compared with Valencia, Spain. The writer is also inclined to attribute the scarcity of the purple scale in Sicily to this same cause. In the United States the purple scale thrives best in Florida and the coast counties of southern California. While rather high temperatures prevail in Florida, there is also much humidity. The distribution of the purple scale at present in the United States is, therefore, limited to sections of more or less moisture. In this respect it is like the black scale, but the black scale does not thrive so well in high temperatures, even if accompanied by much moisture. The purple scale does not yet occur in the interior counties of southern California or in the great valleys of that State. Of course this may be due to the close quarantine that has prevailed in those sections in recent years against the purple scale. But judging entirely from its present distribution, the purple scale appears to be restricted to regions of more or less moisture, or at least to those in which the combination of high temperatures and low humidity does not prevail.

Temperatures at Valencia, Spain, and Palermo, Italy, January, 1910, to August, 1913, inclusive.[1]

	Valencia, Spain.			Palermo, Italy.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
1910.	°F.	°F.	°F.	°F.	°F.	°F.
January	72	37	50	69	35	50
February	79	33	54	71	35	50
March	70	35	52	69	35	52
April	83	32	58	87	39	58
May	84	40	62	79	44	61
June	95	49	70	86	52	68
July	102	52	74	91	55	72
August	99	57	74	91	58	74
September	84	53	62	90	53	69
October	81	43	65	94	50	68
November	79	37	58	87	37	58
December	72	34	53	77	38	55
1911.						
January	66	35	46	64	31	48
February	81	35	51	72	30	49
March	70	33	53	82	34	55
April	88	35	56	80	39	56
May	83	42	63	80	47	62
June	86	53	69	86	52	70
July	98	59	69	92	52	76
August	95	60	77	93	64	79
September	96	55	73	105	56	74
October	80	42	64	93	51	69
November	75	35	55	80	45	62
December	71	33	53	70	38	55
1912.						
January	71	35	51	70	35	52
February	77	33	55	71	37	55
March	84	37	58	73	40	57
April	75	37	57	79	41	57
May	94	43	65	93	45	64
June	86	50	68	87	54	70
July	97	59	74	106	59	77
August	100	48	74	92	57	75
September	96	52	68	83	51	66
October	86	45	63	79	50	64
November	79	33	55	74	42	54
December	70	36	50	68	40	52
1913.						
January	....	....	....	65	37	52
February	....	....	....	67	33	50
March	....	....	....	84	36	54
April	....	....	....	79	40	59
May	....	....	....	85	47	64
June	....	....	....	88	53	70
July	....	....	....	95	56	74
August	....	....	....	107	57	75

[1] In converting centigrade into Fahrenheit, fractions have been discarded.

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BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 135

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
September 10, 1914.

EXPERIMENTS IN THE PRODUCTION OF CROPS ON ALKALI LAND ON THE HUNTLEY RECLAMATION PROJECT, MONTANA.

By Dan Hansen,
Farm Superintendent, Office of Western Irrigation Agriculture.

INTRODUCTION.

On the Huntley Reclamation Project in Montana there is a large area, comprising as much as 6,000 or 7,000 acres, or somewhat less than one-fourth of the area of the project, in which much of the land contains an excess of salt or alkali. There is, of course, much variation in the salt content of this land, but on all of this portion of the project there has been more or less difficulty in getting good results with crops. This salt, which is made up largely of sulphates of soda and lime, has been derived from the weathering of the underlying shale and from leaching from the shale beds which protrude from the higher lands south of the irrigated tract.

Soon after the project was opened to settlement in 1907 it became apparent that some special methods would be required to bring these salty lands into full production. In 1909 the Department of Agriculture established an experiment farm on the Huntley project near the town site of Osborn. At this point the salt content of the soil is not excessive. In order to meet the demand for information as to the best method for reclaiming the salty land, operations were begun in the autumn of 1910 on a tract of 40 acres near the town site of Worden, 4 miles east of the experiment farm. This Worden tract, as it is called, is situated near the center of the badly affected area and is fairly representative of that area.

The surface soil on this tract is a very heavy impervious clay containing alkali salts in amounts that are not tolerated by most crop plants. The physical character of the soil is such as to prevent natural leaching, and there has been an accumulation of the salts in the surface soil. Underlying the surface soil, at depths varying from 5 to 8 feet, is a stratum of sand and gravel.

The land in the affected area is somewhat lower than the surrounding lands of the project and is generally rather level, being broken only occasionally by slight depressions or natural-drainage wasteways. Very little leveling is necessary in preparing the land for irrigation.

The natural vegetation is a low, scattering growth of scrub sage and saltbush and a very little grass. Throughout the entire area are many small spots entirely barren of vegetation. The soil on these barren spots bakes rapidly and becomes very hard after rains.

The lower layers of the soil between the upper foot or two and the underlying gravel contain very little moisture before irrigation water is applied or before they are affected by the rise of ground water. The ground water at the time this work was started in 1910 was 6 to 8 feet below the surface and occurred only in the underlying gravel. This gravel stratum is apparently broken or contains so much fine material that the water entering the soil from the irrigation of higher lands can not be carried off as rapidly as it enters the soil, and there has been a consequent rise of the ground water over this area during the past two years. It rose during the season of 1913 to within about 3 feet of the surface.

It appears that the problem involved in the reclamation of this land is the opening up of the surface soil so as to make possible the leaching out of the alkali salts either by the application of irrigation water or by the rainfall.

This soil is also very deficient in vegetable matter, and it appeared that the addition of humus by plowing under green-manure crops would be one of the best means of improving the physical condition of the soil. Rye appeared to be the best crop for this purpose, as it is able to produce a crop under rather adverse conditions. In the fall of 1910 about 12 acres of the land on this tract were broken up and planted to winter rye. This land lies in two fields. Field M–I contains about 5 acres and field M–II about 7 acres. The rye crop made a fair though rather irregular growth, and was plowed under in June, 1911, when the plants were heading. On the 7-acre field and on a part of the 5-acre field this treatment was repeated in 1912. The second year's crop of rye was much heavier and more uniform than the first. Each year after plowing the rye under, the land was cultivated frequently after rains, to maintain a mulch and to prevent the crusting of the surface. By this method the tilth of the soil appeared to be much improved, and the amount of salt in the surface soil, as shown by determinations made at different dates, was greatly decreased. The land on which the green-manure treatment had been applied for two years was cropped to winter wheat in 1913. The wheat on field M–II yielded 28.7 bushels per acre and that on field M–I 35 bushels per acre. Trials of alfalfa and sugar beets were also made in 1913 on small plats that had received the green-manure treatment. Sugar beets yielded at the rate of 11 tons per acre, and a satisfactory stand of alfalfa was secured, although the success of this crop will, of course, not be known until next season.

It appeared that the leaching out of the salts might be hastened by frequent light applications of irrigation water followed by cultivation after each irrigation. The purpose of this cultivation was to keep the soil opened and to cause the water to move downward through the soil to the underlying gravel.

This irrigation was done by means of the bordered check system in which small plats were bordered and made as nearly level as possible, so that the drying of the soil after irrigation would be uniform, in order that the cultivation would not be delayed. This method was practiced on a series of plats on which one green-manure crop had been plowed under and was continued during a part of the season of 1911 and all of the season of 1912. Determinations made at different times indicated that the total salt content of the soil was at first materially reduced by this method, but that it increased slightly in the lower depths during the latter part of 1913, owing to the rapid rise of the ground water. This land was cropped in 1913 to alfalfa and oats, one plat to each crop. A good stand of alfalfa was secured, and the oats yielded at the rate of 51.6 bushels per acre.

On another series of plats on which the flooding and cultivation treatment was practiced, manure was applied at the rate of 20 loads per acre each year during 1911 and 1912. Determinations of the total salt content of the soil indicate that this method was only slightly more effective in reducing the salt in the soil than the irrigation and cultivation treatment without the use of barnyard manure. The crops grown on this land in 1913 were spring wheat, oats, and sugar beets. Wheat yielded at the rate of 36 bushels, oats at the rate of 68.9 bushels, and beets at the rate of 7.9 tons per acre.

The method of plowing under green manure has apparently been more effective in reducing the salt content of the soil, as indicated by determinations made in 1913, than has either of the other methods tried.

During the latter part of the season of 1912 and during 1913 there has been a rapid rise of the ground water over this area. The average depth during 1913 was about 3 feet, and it is apparent that underground drainage will be required before the benefits of soil treatment can be expected to be permanent.

The experimental work, begun on this tract in 1910, has been continued during three seasons and is still in progress. While the reclamation of the tract is not yet completed, substantial progress has been made, and it seems desirable to publish an account of the work and of the results so far accomplished. A detailed account of the observations made, the experiments conducted, and the results secured is given in the following pages.

QUANTITY AND CHARACTER OF THE SALT.

Determinations of the quantities of salts in this soil have been made with the electrolytic bridge at intervals since this work was started. The samples on which these determinations were made were taken from six different strata, as follows: The first 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, 24 to 36 inches, and 36 to 48 inches. A general idea of the total salt content of the virgin soil can be obtained from the average of 50 samples from each depth taken on five different dates—May 2, June 5, July 16, September 3, and October 23, 1913—from 10 different places on the tract. The total salt content of the soil of each layer (expressed as a percentage of the air-dry soil) was found to be as follows: Top 3 inches, 0.65; 3 to 6 inches, 0.92; 6 to 12 inches, 1.54; average of first foot, 1.16; 12 to 24 inches, 1.83; average of top 2 feet, 1.49; 24 to 36 inches, 2.08; 36 to 48 inches, 1.79; average of top 4 feet, 1.71.

It is seen that the salt content of the virgin soil increases rapidly with the depth. The average of 1.71 per cent for the whole 4-foot layer is equal to 111.73 tons of salts per acre. This percentage is too high to permit normal growth of most field crops. Analyses have been made of the salt in the soil samples taken on May 2[1] from 10 borings. The results of the analyses (expressed as percentages of air-dry soil) of the 10 composite samples are as follows: Total salts, 1.774; CaO, 0.2374; MgO, 0.0698; NO_3, trace; Na_2O, 0.4410; HCO_3, 0.0360; SO_4, 1.2386.

This analysis indicates that the salts are chiefly a mixture of the sulphates of sodium, calcium, and magnesium, and if the results are calculated in terms of these salts they show percentages of salts in the dry soil as follows: Total solids, 1.774; Na_2SO_4, 1.0106; $CaSO_4$, 0.5758; $MgSO_4$, 0.2078.

An analysis of 16 samples of this soil made by Prof. Edmund Burke, of the Montana Agricultural Experiment Station, in 1912, gave the following percentages: Na_2SO_4, 1.1284; Na_2CO_3, 0.02848; NaCl, 0.01956. These analyses show small amounts of sodium carbonate and sodium chlorid, neither of which was found in the samples analyzed in 1913. The samples from which the analyses were made in 1912 were taken from a different part of the field and were from specially selected "bad spots." This might account for the differences found.

[1] These analyses and the analyses of ground water shown in Table I were made by Mr. J. F. Breazeale, of the Bureau of Chemistry, United States Department of Agriculture.

GROUND WATER.

For the purpose of determining the depth of ground water at different times of the year, four wells have been made on the experiment tract, and measurements were made biweekly during 1913. The results of these measurements are shown in figure 1. The average depth to ground water during 1913 was 3.14 feet. This ranged from 3.76 feet on March 6 to 2.02 feet on October 2, the most rapid rise occurring during the latter part of the irrigation season.

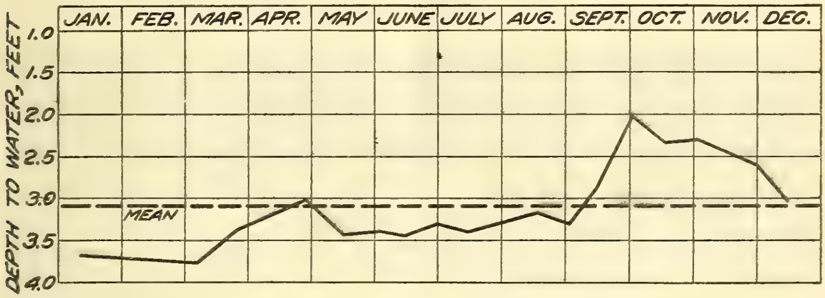

FIG. 1.—Diagram showing the depth to ground water on the Worden tract during the year 1913.

Samples of the ground water were taken from each of these wells during the season of 1913 from June to November, and nine samples from each well have been analyzed. The average results of these analyses are given in Table I.

TABLE I.—*Results of analyses of ground water from the Worden tract in 1913, showing the percentages of the substances indicated.*

Well No.	Total salts.	CaO.	MgO.	Na_2O.	CO_3.	HCO_3.	Cl.	SO_4.
A-1	1.383	0.0549	0.0719	0.437	None.	0.0277	0.0136	0.952
A-2	2.829	.0737	.1289	1.001	None.	.0381	.0294	1.901
B-1	1.512	.0178	.0521	.566	0.0026	.0169	.0109	1.027
B-2	1.165	.0193	.0268	.431	.0096	.0370	.0098	.788
Average	1.722	.0414	.0699	.609	.0030	.0299	.0159	1.167

Table I shows that the water contained an average of 1.722 per cent of total salts and that these consisted chiefly of sulphates. This amount is equal to 1.07 pounds per cubic foot of water. Analysis of the soil showed that it contained an average of 1.77 per cent of total salts. Assuming that a cubic foot of the soil weighs 75 pounds and that it contained an average of 15 pounds of water, this amount would be equal to 1.32 pounds of soluble salts per cubic foot of moist soil, or the concentration of salts in the soil water would be about 9 per cent. This concentration is about five times as great as that of the ground water.

BEHAVIOR OF CROPS ON NEWLY CULTIVATED SOIL.

Crops planted on newly broken land on the farms in this locality have been in most cases partial or total failures. Because of the refractory nature of the soil, it is generally difficult to secure a good stand. Even though a fair stand is secured, the growth of the plants is generally very irregular. (See fig. 2.) A very stunted growth, and

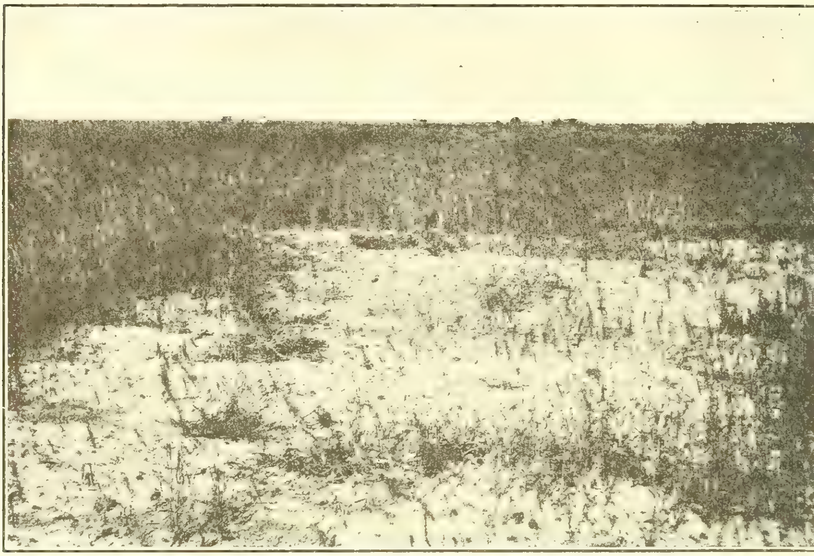

FIG. 2.—Rye in field M-I on June 21, 1911, showing the irregular growth characteristic of crops on the unreclaimed soil.

in some cases no growth at all, occurs on spots that were barren of native vegetation before the ground was broken up.

METHODS OF SOIL TREATMENT.

Three methods of soil treatment were practiced during 1911 and 1912, after plowing under the green-manure crop in 1911, on fields M-I and M-II, as shown in figure 3. Field M-I is divided into 19 plats. Plats 1 to 14, inclusive, are one-fourth of an acre and plats 15 to 19, inclusive, are one-sixth of an acre in size. Field M-II contains $6\frac{3}{4}$ acres, not divided into plats. The three methods are described as follows:

First method.—The first method was a continuation of the treatment applied in 1911. Rye was planted again in the fall of 1911 and was plowed under as green manure in June, 1912. Each season after the rye was plowed under the land was left fallow during the summer and given frequent cultivations with the disk and harrow. This method was applied on plats 1 to 12, inclusive, on field M-I and to all of field M-II. Plats 1, 2, and a part of plat 3 in field M-I were subsoiled in June, 1911. Plats 7, 8, and 9 in field M-I were planted to corn in July, 1911, but the growth was very small and irregular, and no crop was secured.

Second method.—The second method included plowing under rye as green manure in 1911, followed during the latter part of 1911 and all of the season of 1912 by frequent irrigating and cultivating. In September, 1911, the ground was leveled and bordered for irrigating in plats containing about one-sixth of an acre. Each irrigation was followed as soon as possible by cultivation. This treatment was applied on plats 15 and 16 on field M-I.

Third method.—The third method was the same as the second, except that barnyard manure was applied at the rate of 20 loads per acre in 1911 before plowing under the rye, and again in 1912. In 1912 the manure was plowed under in June and the land was immediately leveled. Alternate irrigation and cultivation was practiced during the remainder of the season. This method was applied on plats 17, 18, and 19 on field M-I.

All of the plats included in the three methods were cropped in 1913. The treatments applied in 1913 were simply the ordinary operations in the preparation of the seed bed and the subsequent irrigation and cultivation necessary in growing the different crops.

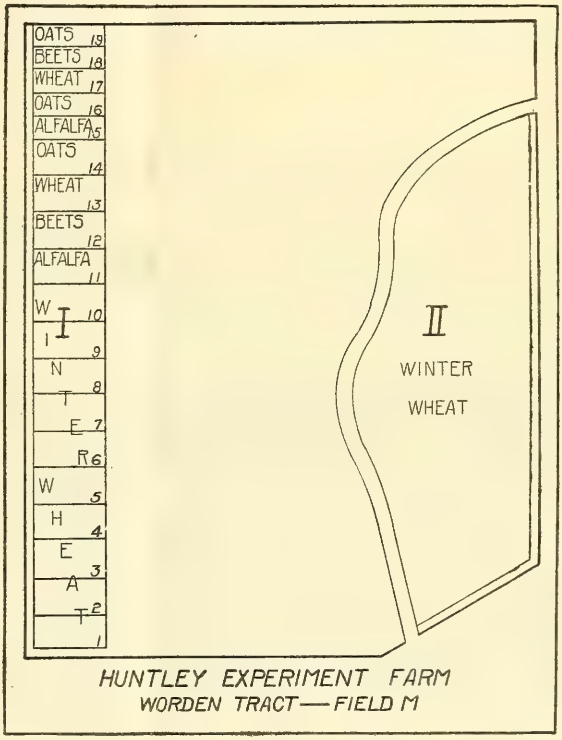

FIG. 3.—Diagram of the Worden tract, showing fields M-I and M-II, where the experiments discussed in this bulletin were carried on and indicating the location of the different crops in 1913.

RESULTS OF EXPERIMENTS.

FIRST METHOD.

Since the soil is very deficient in vegetable matter, it was thought that the addition of humus by plowing under green-manure crops would be one of the best means of opening up the surface soil. This appears to have been the case. As mentioned previously, all of the land on this tract that was broken up in 1910 was planted to winter rye and the crop plowed under in June, 1911. This treatment was repeated in 1912 on part of the land. The second rye crop made a much heavier and more uniform growth than the crop plowed under in 1911 (fig. 4), and the soil tilth appeared to be much improved.

Effect on the salt content.—Total salt determinations were made in May, June, July, September, and October, 1913, with samples taken from plats 2, 5, 7, 9, 11, and 12 in field M–I and from adjacent virgin soil.

A summary of these determinations is given in Table II, which shows the average salt content to a depth of 4 feet in 1913. The results are expressed in percentage of air-dry soil.

TABLE II.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the first method and of adjacent virgin soil.*

Soil.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Cultivated	60	0.23	0.28	0.39	0.32	0.85	0.58	1.31	1.29	0.94
Virgin	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference		.42	.64	1.15	.84	.98	.91	.77	.50	.77

The average difference between the total salt content of the first 4 feet of cultivated soil and that of virgin soil is shown by Table II to

FIG. 4.—Rye in field M-II on June 13, 1912. This was the second crop of rye grown on this land and was much more uniform than the first crop.

have been 0.77 per cent. The largest differences occurred in the first and second feet. The differences are sufficient to show that the treatment given the soil has been decidedly beneficial in reducing the salt content.

It was noted that the soil of plat 2, which was subsoiled in June, 1911, contained somewhat less salt in 1913 than the plats which had not been subsoiled. The average salt content of the soil of five plats which received treatment according to the first method and which were sampled for total salt determinations in 1913 is given in Table III, together with the average salt content of the soil in plat 2.

TABLE III.—*Average total salt content of the soil on five plats not subsoiled and on a subsoiled plat, 1913.*

Plats.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Nos. 5, 7, 9, 11, and 12.	50	0.24	0.30	0.44	0.35	0.89	0.62	1.50	1.48	1.05
No. 2, subsoiled.....	10	.24	.22	.25	.24	.33	.28	.77	.79	.53
Difference.....	....	0	.08	.19	.11	.56	.34	.73	.69	.52

The subsoiled plats showed little advantage in yield, however. The average yield of winter wheat on two plats subsoiled was at the rate of 35 bushels per acre, while the average of seven plats not sub-

FIG. 5.—Winter wheat in field M-II on July 14, 1913. In 1911 and 1912 a crop of rye was plowed under on this field as green manure, according to the first method. The winter wheat in this field yielded 28.7 bushels per acre in 1913.

soiled was 34.7 bushels per acre. Subsoiling is a difficult and expensive operation, and it is doubtful whether the differences in salt content, as shown above, are of sufficient importance to indicate that subsoiling would be profitable.

Crops grown in 1913.—Winter wheat, alfalfa, and sugar beets were grown on this land in 1913. Ten plats of winter wheat and one plat of each of the other crops were planted. At the time of planting winter wheat, in September, 1912, the ground was in excellent tilth. This crop made a much more uniform growth than the preceding crop of rye. (See fig. 5.) The alfalfa and sugar beets were planted on May 6, 1913. A good stand of alfalfa was secured and the crop was clipped on September 6. The yields of these crops are given in Table IV.

TABLE IV.—*Average yields obtained in 1913 from land treated according to the first method.*

Field.	Crop.	Area.	Variety.	Unit of yield.	Yield per acre.		
					Maximum.	Minimum.	Average.
M[illegible]	Winter wheat	10 quarter-acre plats.	Kharkof	Bushel	41.31	29.4	34.96
M-[illegible]	do	6¾ acres	do	do			28.70
M-[illegible]	Sugar beets	1 quarter-acre plat	Kleinwanzlebener	Ton			10.97
M-[illegible]	Alfalfa	do	Montana	do			.22

While the yields are not high, they are considered very satisfactory, coming from land which had previously been unproductive. They indicate that, so far as the surface soil is concerned, the land has been fairly well reclaimed.

Cost of the method.—A record has been kept of the work done on this land from the first plowing in 1910 to the end of the season of 1912. In order to get an idea of the cost of the treatment, the different operations applied to the land have been listed and the cost of each has been estimated. The figures are given in Table V.

TABLE V.—*Estimated cost per acre of reclaiming land that received treatment according to the first method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (2 times at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95
1911.		
Irrigating (once)	.40	
Plowing rye under	4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (3 times at 25 cents each)	.75	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1911		9.60
1912.		
Plowing rye under	4.00	
Double disking (once)	1.00	
Harrowing (3 times at 25 cents each)	.75	
Total for 1912		5.75
Total for 3 years		24.30

SECOND METHOD.

The practice of alternate irrigation and cultivation was not started until September, 1911. The season was then so far advanced that it was not possible to accomplish much during the remainder of that year. This practice was continued during the season of 1912 from May until September, the land being cultivated and irrigated at about 10-day intervals. The cultivating was done with a beet cultivator equipped with bull-tongue shovels, and the ground was leveled with a float before each irrigation.

Effect on the salt content.—Determinations, by means of the electrolytic bridge, were made of the total salts in the soil on these plats during the seasons of 1911, 1912, and 1913. Samples were taken at irregular intervals in 1911 and 1912. In 1913 complete sets of samples were taken in May, June, July, September, and October. In 1911 and 1912 samples of the following layers of soil were taken: Top 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, and 24 to 36 inches. In 1913 samples were taken of the same layers and also of the 36 to 48 inch layer. It was found, however, that the salt content at 48 inches did not differ materially from that at 36 inches, so that only the surface 36 inches of soil are considered in the comparisons here given. Table VI shows the average salt content at specified depths in 1911, 1912, and 1913 expressed as percentages of air-dry soil.

TABLE VI.—*Average total salt content of soil to a depth of 3 feet on plats which had received treatment according to the second method in 1911, 1912, and 1913.*

Year.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	Average, top 3 feet.
1911	32	0.31	0.36	0.54	0.43	1.30	0.86	2.07	1.26
1912	36	.26	.33	.51	.40	.89	.64	1.68	.99
1913	40	.25	.34	.60	.44	1.01	.72	1.75	1.07

A study of Table VI shows that there was a reduction of 0.27 per cent in the average salt content of the upper 3 feet of soil from 1911 to 1912 and that there was an increase in 1913 over 1912 of 0.08 per cent. This increase occurred mainly in the second and third feet and accompanied the rise of the ground-water table during 1913.

In Table VII the average salt content to a depth of 4 feet in 1913 on these plats is compared with the average salt content of adjacent virgin soil in the same year. The samples were taken in May, June, July, September, and October, and the results are expressed in percentages of air-dry soil.

TABLE VII.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the second method and of adjacent virgin soil in 1913.*

Treatment.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Second method	40	0.25	0.34	0.60	0.44	1.01	0.72	1.75	1.45	1.16
Virgin soil	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference	....	.40	.58	.94	.72	.82	.77	.33	.34	.55

Table VII shows that there was in the first 4 feet an average difference of 0.55 per cent between the salt content of the cultivated soil and that of the virgin soil and that the largest differences were found in the first and second feet.

Crops grown in 1913.—In 1913 alfalfa and oats were planted on this ground, one plat to each crop. The oats yielded at the rate of 51.6 bushels per acre. (See fig. 6.) A good stand of alfalfa was secured, and this crop was clipped once, yielding at the rate of 360 pounds per acre. The success of the alfalfa planting will of course not be known until the crop is older and the plants deeper rooted, but the fact that a good stand has been secured is an encouraging indication.

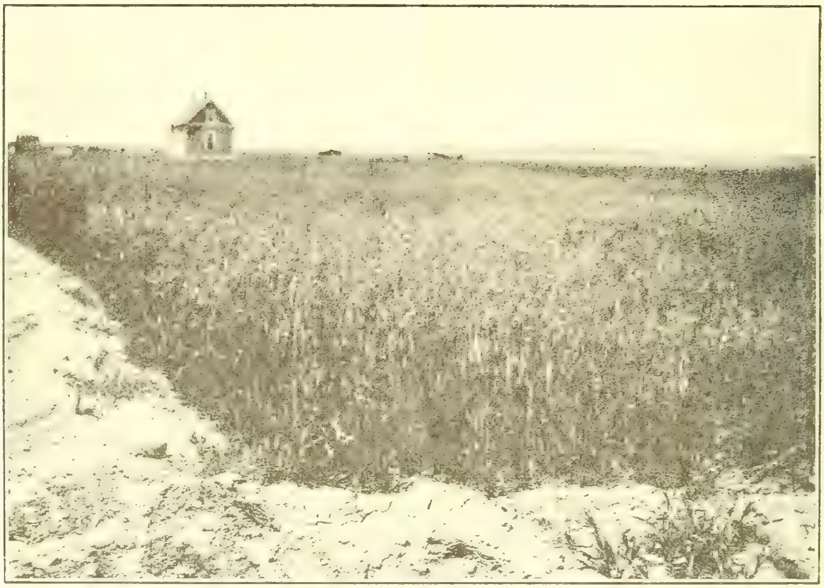

FIG. 6.—Oats on plat 16, in field M-I, on July 14, 1913. This plat received treatment according to the second method. In 1913 oats yielded at the rate of 51.56 bushels per acre.

Cost of the method.—The operations applied in the second method during 1910, 1911, and 1912 are listed in Table VIII, together with the approximate cost per acre of each operation and the total approximate cost per acre for each year and for all three years.

TABLE VIII.—*Approximate cost per acre of reclaiming lands by the second method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (2 times at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95

TABLE VIII.—*Approximate cost per acre of reclaiming lands by the second method*—Con

Year and item of cost.	Cost.	Total.
1911.		
Irrigating (once, in spring)	$0.40	
Plowing rye under	4.00	
Grading and bordering plats	4.00	
Irrigating (4 times at 40 cents each)	1.60	
Cultivating and leveling (4 times at $1.50 each)	6.00	
Total for 1911		$16.00
1912.		
Cultivating and leveling (8 times at $1.50)	12.00	
Irrigating (8 times at 40 cents)	3.20	
Total for 1912		15.20
Total for 3 years		40.15

THIRD METHOD.

In the third method the same treatment as that described in the second method, that of alternate irrigating and cultivating, was applied, and, in addition to this, manure was applied before plowing rye under at the rate of 20 loads per acre in 1911 and again in 1912. During the summer of 1912 the land was irrigated and cultivated at about 10-day intervals.

Effect on the salt content.—Determinations of the total salt content in the soil on these plats were made during 1911, 1912, and 1913. In 1911 and 1912 samples of the following layers of soil were taken at irregular intervals and at depths as follows: Top 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, and 24 to 36 inches. In 1913 complete sets of samples were taken in May, June, July, September, and October. The 1913 samples were taken to a depth of 48 inches, but it was found that the salt content at this depth was practically the same as that at 36 inches, so that only the surface 36 inches are considered in Table IX, in which the average salt content at the specified depths in 1911, 1912, and 1913 are given, the results being expressed as percentages of the air-dry soil.

TABLE IX.—*Average total salt content of soil to a depth of 3 feet on plats which had received treatment according to the third method in 1911, 1912, and 1913.*

Year.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	Average, top 3 feet.
1911	28	0.34	0.43	0.59	0.48	1.28	0.88	2.28	1.35
1912	36	.24	.28	.36	.31	.68	.49	1.21	.73
1913	60	.25	.29	.43	.35	.74	.54	1.37	.82

The reduction of the average salt content in the upper 3 feet of soil on these plats from 1911 to 1912 was 0.62 per cent. There was a slight increase in 1913 over 1912. This increase occurred mainly in the lower depths and accompanied the rise of ground water during the season of 1913.

In Table X the average salt content to a depth of 4 feet in 1913 on these plats is compared with the average salt content of the virgin soil of adjacent plats in the same year. The samples were taken in May, June, July, September, and October, and the results are expressed in percentages of air-dry soil.

TABLE X.—*Average total salt content of soil to a depth of 4 feet on cultivated plats compared with adjacent virgin soil in 1913.*

Treatment.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Cultivated	60	0.25	0.29	0.43	0.35	0.74	0.54	1.37	1.59	1.01
Virgin	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference		.40	.63	1.11	.81	1.09	.95	.71	.20	.70

As shown by Table X, there was a difference of 0.70 per cent between the total salt content of the cultivated soil and that of the virgin soil. The greatest differences were found in the first and second feet.

Crops grown in 1913.—The crops grown on this land in 1913 were spring wheat, sugar beets, and oats, one plat being planted to each crop. The yields secured are given in Table XI.

TABLE XI.—*Yield of crops grown in 1913 on land treated according to the third method.*

Crop.	Variety.	Unit of yield.	Yield per acre.
Spring wheat	Pringle's Champion	Bushel	36.00
Sugar beets	Kleinwanzlebener	Ton	7.86
Oats	Swedish Select	Bushel	68.87

Cost of the method.—The operations applied in the third method during 1910, 1911, and 1912, together with the approximate cost per acre of each operation and the total approximate cost per acre each year and for all three years, are shown in Table XII.

TABLE XII.—*Approximate cost per acre of reclaiming land on the Worden tract by the third method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times, at $1 each)	2.00	
Harrowing (2 times, at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95

TABLE XII.—*Approximate cost per acre of reclaiming land on the Worden tract by the third method*—Continued.

Year and item of cost.	Cost.	Total.
1911.		
Irrigating (once, in spring)	$0.40	
Manuring (20 loads, at 50 cents a load)	10.00	
Plowing rye under	4.00	
Grading and bordering plats	4.00	
Irrigating (2 times, at 40 cents each)	.80	
Cultivating and leveling (3 times, at $1.50)	4.50	
Total for 1911		$23.70
1912.		
Manuring (20 loads, at 50 cents a load)	10.00	
Plowing	4.00	
Double disking	1.00	
Harrowing	.25	
Leveling	.75	
Irrigating (6 times, at 40 cents)	2.40	
Cultivating and leveling (6 times, at $1.50)	9.00	
Total for 1912		27.30
Total for 3 years		59.95

COMPARISON OF THE THREE METHODS.

Effect on salt content.—In comparing the efficiency of the different methods of reclaiming this land, the effect on the amount of total

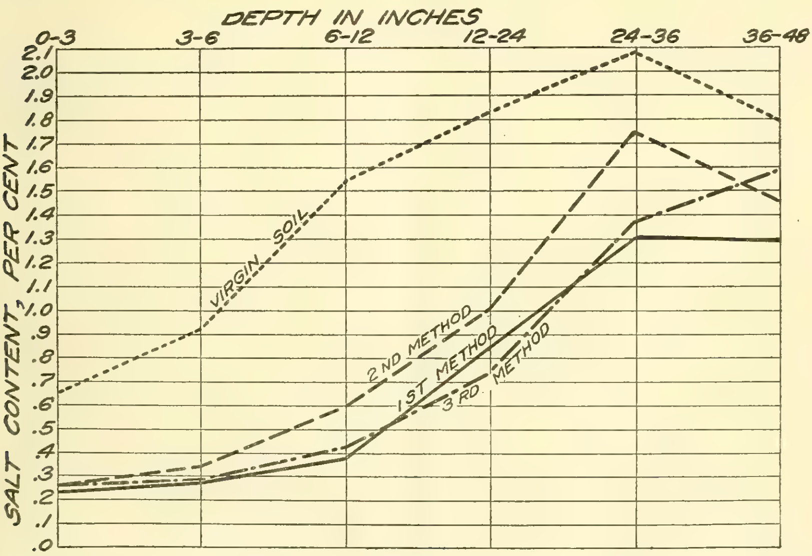

FIG. 7.—Diagram showing the average total salt content of the soil at six depths in 1913 on plats which had received treatment according to the first, second, and third methods, respectively, and of adjacent virgin soil.

salts contained in the surface 4 feet of soil will be considered first, Table XIII gives the average salt content to a depth of 4 feet in 1913, and figure 7 shows graphically the same results. These samples were taken on May 2, June 5, July 16, September 3, and October 23, 4-foot borings being made on each date.

TABLE XIII.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the first, second, and third methods, respectively, and of adjacent virgin soil, in 1913.*

Soil.	Method.			Virgin soil.
	First.	Second.	Third.	
Number of borings	60	40	60	50
Layer of soil:				
Top 3 inches	0.23	0.25	0.25	0.65
3 to 6 inches	.28	.34	.29	.92
6 to 12 inches	.39	.60	.43	1.54
Average, first foot	.32	.44	.35	1.16
12 to 24 inches	.85	1.01	.74	1.83
Average, top 2 feet	.58	.72	.54	1.49
24 to 36 inches	1.31	1.75	1.37	2.08
Average, top 3 feet	.83	1.07	.82	1.69
36 to 48 inches	1.29	1.45	1.59	1.79
Average, top 4 feet	.94	1.16	1.01	1.71

From Table XIII and figure 7, it appears that the first method, that of plowing under rye as green manure and keeping the soil clean cultivated after plowing, has been the most effective in reducing the salt content of the upper 4 feet of soil. It appears also that the third method, alternate irrigating and cultivating combined with heavy applications of barnyard manure, has been second in effectiveness. This is assuming that the amount of salts was the same on all parts of the field before the ground was broken up in 1910. No determinations were made of the salt content before the ground was broken up.

Crops grown in 1913.—It is not possible to make direct comparisons of the crop returns secured in 1913 on the plats which had received different treatments in previous years. As already shown, the plats receiving the treatments according to the first method produced very satisfactory results with winter wheat, sugar beets, and alfalfa; those treated by the second method produced fair returns from oats and alfalfa; and the plats treated in accordance with the third method produced spring wheat and oats satisfactorily and a fair yield of sugar beets. The chief point to be considered in connection with the crop returns in 1913 is that the behavior of all the crops grown indicated that the soil on all the plats which have received treatment has been greatly benefited, and that so far as the surface soil is concerned the treated land has been fairly well reclaimed. Whether the reclamation is to be permanent will depend on future conditions, of which drainage is probably the most important.

Cost.—A comparison of the approximate cost per acre of the different methods is given in Table XIV.

TABLE XIV.—*Approximate cost per acre of reclaiming land according to the first, second, and third methods, respectively.*

Year and item of cost.	Method.		
	First.	Second.	Third.
1910.			
Breaking	$4.00	$4.00	$4.00
Double disking (2 times, at $1)	2.00	2.00	2.00
Harrowing (2 times, at 25 cents)	.50	.50	.50
Leveling	.75	.75	.75
Seeding	.50	.50	.50
Seed	1.20	1.20	1.20
Total for 1910	8.95	8.95	8.95
1911.			
Irrigating (once, in spring)	.40	.40	.40
Manuring (20 loads, at 50 cents a load)			10.00
Plowing rye under	4.00	4.00	4.00
Double disking (2 times, at $1)	2.00		
Leveling and bordering		4.00	4.00
Harrowing (3 times, at 25 cents)	.75		
Irrigating (at 40 cents each time)		1.60	.80
Cultivating and leveling (at $1.50 each time)		6.00	4.50
Leveling	.75		
Seeding	.50		
Seed	1.20		
Total for 1911	9.60	16.00	23.70
1912.			
Manuring (20 loads, at 50 cents a load)			10.00
Plowing	4.00		4.00
Double disking	1.00		1.00
Harrowing (at 25 cents each time)	.75		.25
Leveling			.75
Irrigating (at 40 cents each time)		3.20	2.40
Cultivating and leveling (at $1.50 each time)		12.00	9.00
Total for 1912	5.75	15.20	27.30
Total for 3 years	24.30	40.15	59.95

It is shown in Table XIV that the first method was by far the least expensive of the three; that the second method, which involved a large amount of work in irrigating and cultivating, was next higher in cost; and that the third method, which differed from the second mainly in that it included an item of $20 per acre for manuring, was the most expensive of all.

SUMMARY.

(1) The surface soil on an area of approximately 7,000 acres, or about one-fourth of the Huntley project, is a heavy, impervious clay, containing alkali salts in amounts that are not tolerated by most crop plants. The total salt content of the virgin soil to a depth of 4 feet on the experiment tract averages about 1.7 per cent and consists principally of the sulphates of sodium, calcium, and magnesium.

(2) Underlying the surface soil at depths ranging from 5 to 8 feet is a stratum of sand and gravel.

(3) During 1912 and 1913 ground water has accumulated in the soil, and the ground-water level on the experiment tract has risen to

within 2 to 3 feet of the surface. This ground water contains about 1.7 per cent of salts in solution.

(4) The reclamation of the land depends on the opening up of the surface soil, so as to make possible the leaching out of the salts by the application of water, and on the drainage of the land to lower permanently the ground-water level.

(5) Experiments to determine a satisfactory method of opening up the surface soil and leaching out the salts have been conducted since 1910. Three methods have been tried:

1. Green manuring with rye, followed by the cultivation necessary to maintain a soil mulch.
2. Green manuring with rye in 1911, followed by frequent irrigation and cultivation in 1911 and throughout the season of 1912.
3. Green manuring with rye in 1911 and barnyard manuring in 1911 and 1912, combined with frequent irrigation and cultivation in 1911 and 1912.

(6) All three methods have been decidedly beneficial. The greatest reduction in the salt content resulted from the first method, the next greatest from the third method, and the least from the second method.

(7) In 1913 satisfactory crops of wheat, oats, beets, and alfalfa were produced on land which had received treatment, indicating that in so far as the surface soil is concerned the land has been fairly well reclaimed. Whether the reclamation is to be permanent will depend on future conditions, of which drainage is probably the most important.

(8) The cost of the first method was $24.30 per acre, that of the second method $40.15 per acre, and that of the third method $59.95 per acre.

(9) Considering both effectiveness and cost, the first method appears to be the best of the three.

PRACTICAL SUGGESTIONS.

Cultural directions for green manuring with rye.—Rye may be planted on this soil immediately after breaking, as was done on this tract in 1910, although it is generally difficult at first to obtain a good seed bed. It is likely that breaking earlier in the season—in June or July—and keeping the ground thoroughly cultivated with the disk and harrow after rains, would leave it in better condition at seeding time. In any case it is necessary to work the soil thoroughly with the disk and harrow before seeding. To insure a good stand it is advisable to seed rather heavily. From 1½ to 2 bushels of seed to the acre should be used. Seeding should be done, if possible, in early September, although it might be possible to secure a good stand by planting as late as October. The effect of time of seeding depends very much on the season.

In ordinary seasons irrigation will probably not be necessary. If practiced at all, it should be done so early that the ground will not be too wet for plowing at the time the crop is ready to plow under. To obtain the maximum amount of growth, plowing should be deferred until the rye is well headed, but the land should be plowed before the grain has begun to fill. Fairly deep plowing—from 7 to 10 inches—is necessary in order to cover the green-manure crop thoroughly. In plowing the crop under, a chain or rod attached to the plowbeam ahead of the plow will turn all of the rye into the furrow, so that it will be well covered. After plowing, it is advisable to disk and harrow the ground thoroughly. Cultivation during the summer after every rain of any consequence is necessary in order to prevent crusting and to keep the soil in good tilth.

Requirements for permanent reclamation.—Before any permanent benefit can be expected from any method of soil treatment it will be necessary that adequate drainage be provided in all cases where the water table has risen to within 3 or 4 feet of the surface. Where drainage systems have been installed, irrigation by means of the bordered plat system to promote leaching, together with frequent cultivation, should also prove effective in washing out the alkali salts.

The time required for reclaiming these lands will depend upon the amount of salts in the soil and the condition of the soil. It seems likely, from the results so far obtained, that treatments covering from one to three years will be necessary before satisfactory crop returns can be expected.

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No. 136

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February 12, 1915.

HIGHWAY BONDS:

A COMPILATION OF DATA AND AN ANALYSIS OF ECONOMIC FEATURES AFFECTING CONSTRUCTION AND MAINTENANCE OF HIGHWAYS FINANCED BY BOND ISSUES, AND THE THEORY OF HIGHWAY BOND CALCULATIONS.

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HIGHWAY BONDS:

A COMPILATION OF DATA AND AN ANALYSIS OF ECONOMIC FEATURES AFFECTING CONSTRUCTION AND MAINTENANCE OF HIGHWAYS FINANCED BY BOND ISSUES, AND THE THEORY OF HIGHWAY BOND CALCULATIONS.

By LAURENCE I. HEWES, *Chief, Economics and Maintenance, Office of Public Roads*, and JAMES W. GLOVER, *Professor of Mathematics and Insurance, University of Michigan, Collaborator, Office of Public Roads.*

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INTRODUCTION.

The practice of issuing bonds for highway and bridge construction by counties and their subdivisions has become common. In 1,230 counties, or 41.1 per cent of all the counties in this country, there were outstanding highway bonds on January 1, 1914. The total amount of such bonds voted,[1] as ascertained by the Office of Public Roads up to that date, was $286,557,073, of which township bonds alone amounted to $57,153,718. The amount of outstanding local highway bonds on January 1, 1913, was approximately $202,007,776. This amount was increased during the year 1913 by current issues noted below, but was also slightly decreased by maturing payments.

The county highway bond is essentially a municipal bond; that is, a bond issued by a public corporation. Statistics indicate that all municipal bonds constitute about 20 per cent of the total of all bonds issued, while Government bonds are about 10 per cent. Municipal bonds are regarded as excellent investments and are frequently used by banks as a second reserve. The amount of highway bonds issued is indicated by comparison with the $79,741,688 of irrigation and drainage bonds authorized in the interval from 1907 to 1912, inclusive.

[1] "Voted" is almost equivalent to "issued," except in State highway bonds. The difference between bonds voted and bonds sold in 1912 was a little over 3 per cent.

The progress of the local highway-bond movement is further indicated by the diagram of first issues for the interval 1900–1913. Dates of first issues were reported, however, for only 579 counties. First issues for 1912 and 1913 are practically complete. (Pl. I, fig. 1.)

During the past three years county, district, and township highway and bridge bonds were voted as follows: 1911, $29,200,022; 1912, $32,022,703; 1913, $50,445,756; making a total of $111,668,481.

There have also been voted State highway bonds which now total $158,590,000.[1] The grand total of all highway bonds voted and reported to the Office of Public Roads to January 1, 1914, is, therefore, $445,147,073.

There is given in Appendix A of this publication a list of all the State highway bonds with their dates of issue, terms, and nominal interest rates, together with other pertinent information concerning the issues.

In Appendix B are given three lists of local highway and bridge bonds. First there is a list of county and district highway and bridge bonds voted to January 1, 1914, with their terms and interest rates where reported. A similar table of township bonds is next presented. In a separate table is a list, by counties, districts, and townships in the several States, of highway and bridge bonds reported voted during each of the years 1912 and 1913.

The approximate distribution of local highway bonds is shown in the map, Plate II, by counties. State highway bonds are not included.

In collecting data for this publication the Office of Public Roads corresponded directly with county and township officials and the tables of bonds were submitted to State highway officials and other State officials for corrections and additions. Many county officials failed to state the term of the highway bond issues; it was found, however, that the mean term for approximately $47,000,000 issued prior to 1913 was 24.8 years. For the years 1912 and 1913, the term of issue, the number of issues, and the total amount issued by municipalities with complete reports are presented in the following table:

TABLE 1.—*Bond issues during 1912 and 1913 in counties, districts, and townships, with complete returns.*

Total number of issues.	Terms of issues.	Total amounts of issues.
17	5-year	$442,175
100	10-year	5,165,383
13	15-year	1,266,500
68	20-year	8,906,538
31	25-year	5,518,150
45	30-year	7,399,000
129	Serials	15,300,819
47	Above 30-year	7,170,971
47	Other term	1,816,541

[1] Including $3,415,000 issued by Connecticut, Massachusetts, and New Hampshire in 1913. Massachusetts authorized, in 1912, $5,000,000 to be issued during the years 1913 to 1917, inclusive, which is part of the total given. New York's second $50,000,000 will probably not be entirely issued for several years.

These figures represent 61.2 per cent of all the counties, townships, and districts reporting bond issues during 1912 and 1913.

The reports on the mileage of road constructed from the proceeds of local bond issues are very incomplete and in many instances contradictory. After eliminating all reports which were obviously incorrect or defective, a list of counties and districts giving complete returns of classified mileage of roads constructed has been made. A similar list for township work has also been made. These two lists are presented in Appendix B. It is quite probable that omissions in reports from counties and their subdivisions concerning mileage built are due in part to the frequent changing of local officials.

It will be seen from the diagram of first issues (Pl. I, fig. 1) and from the fact that probably over 80 per cent of local bonds for highways and bridges are still outstanding (see p. 3), that the highway bond movement has yet to meet the test of repayment. The maximum outlay for retirement of outstanding highway loans will apparently be reached in about 20 years.

If highway bond issues are to continue successfully, certain fundamental principles require attention. They are, therefore, discussed briefly in this publication. Necessary information is presented in considerable detail with illustrations and tables to guide highway officials in borrowing and expending highway funds.

COUNTY HIGHWAYS.

The highways of a county may usually be classified into main market roads, intercounty roads, and neighborhood roads. A relatively large percentage of the total mileage—more than 80 per cent in many counties—may be classed as neighborhood roads, which are either feeders to market roads or crossroads of relatively small importance. The intercounty roads are usually in part also main market roads. The market roads are, therefore, the roads for which the question of borrowing money frequently arises. The total mileage of main market roads varies greatly from county to county, but usually does not exceed 150 miles.

The distribution and individual lengths of market roads is of much importance to the highway engineer, who must plan for improvements. Rules can not be laid down which will apply universally for the selection of such roads. The area served by a given market road depends upon the length of the road and the form of the road network, which, in turn, is largely governed by topography and the situation of shipping points. In regions where the public land survey system prevails the roads very generally follow the section lines and radial roads are not common.

It is usual to find from four to eight main market roads radiating from market centers. The average number of such roads of considerable length is about six for each shipping point. The traffic on radial roads will tend to vary inversely with their number. Plates IV, VI, and IX show the distribution of the main market roads in three counties.

ECONOMIC VALUE OF THE MARKET ROAD.

The service rendered by highways radiating from a town may be measured directly by the tonnage which is hauled over them; and their economic importance is indicated by this tonnage and varies directly with it. There are two ways of computing the tonnage of traffic on a road: (a) By actual count, and (b) by determining traffic areas supplemented with producers' and merchants' estimates of tonnage.

The actual count of traffic determines the average number of teams hauling produce each day, their loads, and the average distance traveled. From the count on a sufficient number of days a close estimate of the average annual traffic may be had.

TABLE 2.—*Traffic record of seven unimproved roads.*

Road No.	Location.[1]	Length in miles.	Tons per day, each area.	Average haul (nearest mile).	Equivalent annual ton-miles.	Merchants' and producers' estimates (ton-miles).	Traffic area (acres).	Reported costs (cents per ton-mile).
1	Lauderdale County, Ala. (2)	28.3	58	10	367,894	228,046	154,432	16.0
2	Boone and Story Counties, Iowa (16)	45.1	10	2	162,342	105,662	113,521	37.2
3	Cumberland and Sagadahoc Counties, Me. (8)	32.1	18	4	227,451	....	38,182	23.6
4	Leflore County, Miss. (3)	24.1	33	7	197,386	90,628	60,736	36.2
5	Montgomery County, Md. (1)	5.4	21	2	14,044	5,892	12,531	26.0
6	Muskingum County, Ohio (2)	20.9	28	6	111,026	132,711	41,952	28.0
7	Jackson County, Oreg. (3)	50.5	11	4	51,810	32,170	73,881	36.6
	Totals and averages	206.4	26	5	1,131,953	....	495,235	29.1

[1] Numbers in parentheses indicate the number of traffic areas.

From a map, supplemented by field observations, the traffic area served by a highway may be determined. This is the area on which originates market produce and for which supplies must be hauled from market. In a wheat country, for example, the average annual wheat acreage tributary to a highway will determine approximately the principal market traffic. Even a rough estimate of the traffic area is valuable for determining the relative importance of highways and indicates the order in which their improvement should be undertaken. It is also an excellent check on traffic count. Traffic data for a number of roads recently investigated by the

Office of Public Roads are given in Table 2. Actual traffic count was made four times for seven consecutive days on all the roads. The traffic areas, traffic estimates, and the hauling-cost data were determined in the field. The weight derived from loaded teams and motor trucks only is entered in this table, and the ton-mile hauling costs include a slight increment for loading and unloading.

Highway improvement with borrowed money must be regarded as an investment. The only way, however, that a measurable income arises from the investment is by the reduction of hauling costs. From the standpoint of public economy the annual cost of hauling represents the operating expenses of the road system. The direct return upon the highway investment, then, is the reduction in operating expenses. This difference between the old hauling costs and the hauling costs over the improved roads is a real saving to the community. In the language of railroad bookkeeping, this difference is an operating income to the community. It is invariably true that the improvement of market roads is followed by an increase in annual tonnage, so that estimates based on the existing tonnage are usually conservative. Doubtless much more money can be spent for well-planned and well-built roads without overcapitalizing them.

The unit in which hauling costs are measured is the ton-mile. The cost of hauling a ton 1 mile on a poor road probably varies on an average from 20 to 35 cents. (See Table 2.) It depends on the condition of the road and changes greatly during the year. Recent figures for hauling over unimproved roads in the mountain regions of West Virginia and Kentucky also show seven instances where the cost per ton-mile varied from 23 to 37 cents. Ton-mile costs as low as 10 cents are common in Europe on first-class highways. Even with the extreme variations of wages it is doubtful if the cost per ton-mile anywhere in this country on an adequately improved road exceeds 15 cents. Cross ties were hauled over improved gravel roads in Spotsylvania County, Va., in April, 1913, for about 12.7 cents and less per ton-mile, and apples were hauled by motor trucks on good roads in Jackson County, Oreg., in October, 1913, for a little more than 11 cents a ton-mile.

To understand how many tons a highway can carry in a year, assume a market town from which radiate six roads uniformly distributed and 12 miles long. There is then a circular traffic area of 12 miles radius and each road serves theoretically one-sixth of this area, which is 75.4 square miles. The average haul for each separate road is about 8 miles. (See p. 8.) If each acre tributary to this road supplies only 200 pounds of produce, which must move to market an average distance of 8 miles, the road carries an annual traffic of at least 38,605 ton-miles. Another way to view this traffic is to divide the total number of tons by the number of hauling days, which is usually taken at 300. With an acreage yield of 200 pounds there result 16 tons per day which may be assumed to move an average distance of 8 miles. This would make a total of 128 ton-miles daily. The daily average weight over the entire road is therefore about 10.7 tons. The tonnage hauled is the most direct and reliable basis from which to determine the economic value of a road. (See Table 2.)

It is common to find that when a poor market road is improved the cost of hauling is reduced by from 2 to 10 cents per ton-mile. The saving to the community during a year can then be readily computed for each mile. (See Pl. III, fig. 2.)

Table 3 shows the annual saving per mile and the capitalized amount of this annual saving at 5 per cent interest for daily traffic varying from 5 to 80 tons.

TABLE 3.—*Annual saving per mile in hauling costs at 5 cents per ton-mile reduction.*

Tons per day.	Total saved in year of 300 days.	Capitalized at 5 per cent.	Tons per day.	Total saved in year of 300 days.	Capitalized at 5 per cent.
5	$75	$1,500	45	$675	$13,500
10	150	3,000	50	750	15,000
15	225	4,500	55	825	16,500
20	300	6,000	60	900	18,000
25	375	7,500	65	975	19,500
30	450	9,000	70	1,050	21,000
35	525	10,500	75	1,125	22,500
40	600	12,000	80	1,200	24,000

If the roads do not radiate uniformly from a town it is evident that in a uniformly producing area the traffic lost to one road must go over some adjoining road. However produce is distributed along the road, in general, the portion of the road nearer the market will receive much more use than the distant portion. The first few miles of radial road from a town are also much used by vehicles other than market vehicles.

Although a very important matter, the average haul on a market road is somewhat difficult to determine. It may be estimated from the maximum haul or the known radius of the traffic area,[1] and may usually be assumed to be two-thirds of the average maximum haul.

To show further the service which market roads render to a community, there is given in Table 4 the yearly and daily tonnage pass-

[1] In Bulletin No. 49 of the Bureau of Statistics of the U. S. Department of Agriculture, entitled "Cost of Hauling Crops from the Farms to Shipping Points," the average haul is assumed to be the radius of the circle whose area is one-half the area of a circle whose radius is the maximum haul. The average haul is then about seventy-one hundredths of the maximum haul. If all produce on a traffic area of one-sixth of a complete circle were hauled directly from the point where it originates to the market at the center, the resulting average haul would be sixty-seven hundredths of the maximum haul, which is the radius of the sector. If all produce were first concentrated on the middle radius of the sector, the average haul resulting would be sixty-four hundredths of the radius.

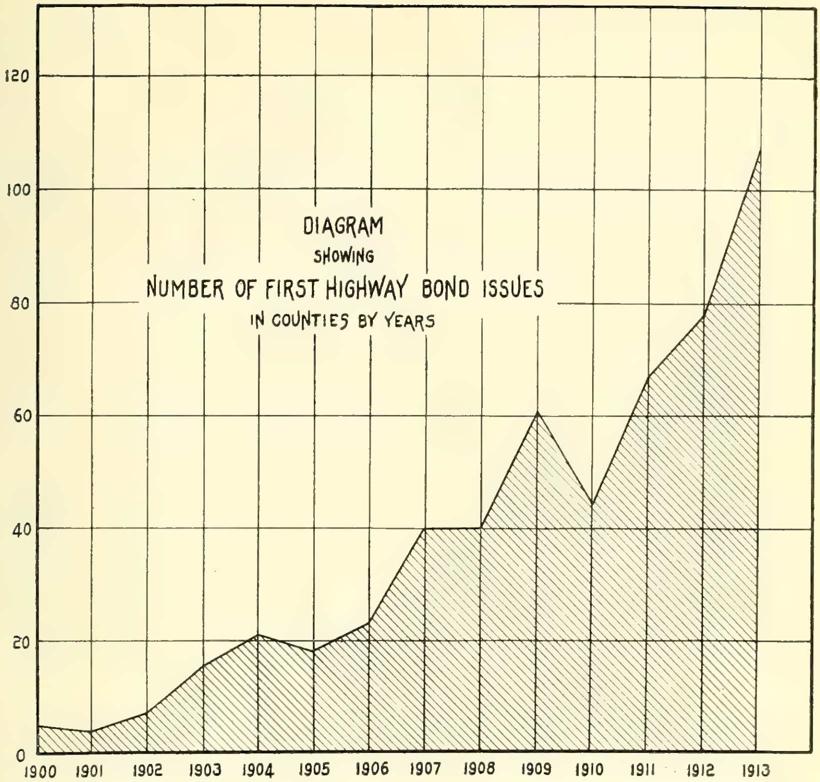
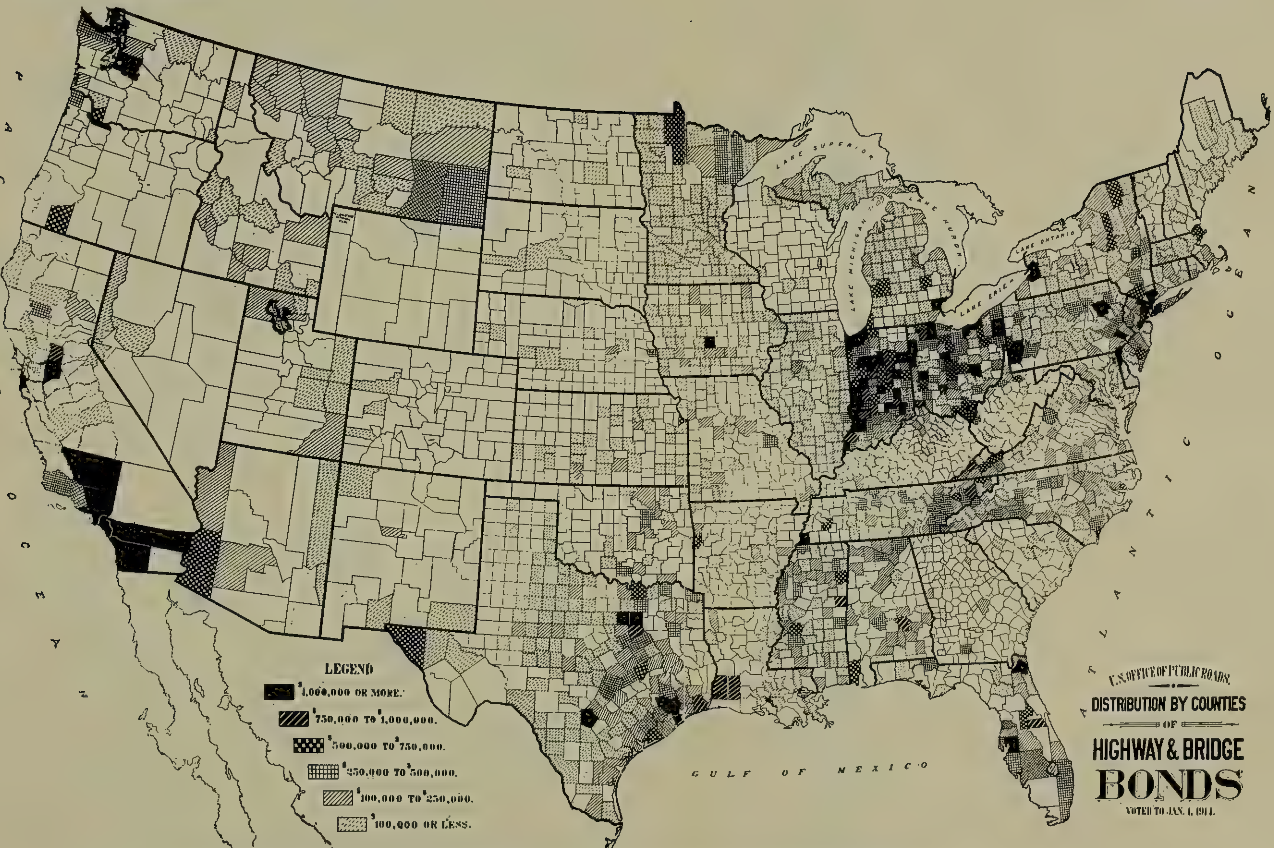


FIG. 1.—DIAGRAM SHOWING NUMBER OF FIRST HIGHWAY BOND ISSUES IN COUNTIES BY YEARS.

FIG. 2.—POOR MACADAM CONSTRUCTION OF 1911 AFTER 1 YEAR.



MAP OF THE UNITED STATES SHOWING THE DISTRIBUTION BY COUNTIES OF HIGHWAY AND BRIDGE BONDS VOTED TO JANUARY 1, 1914.

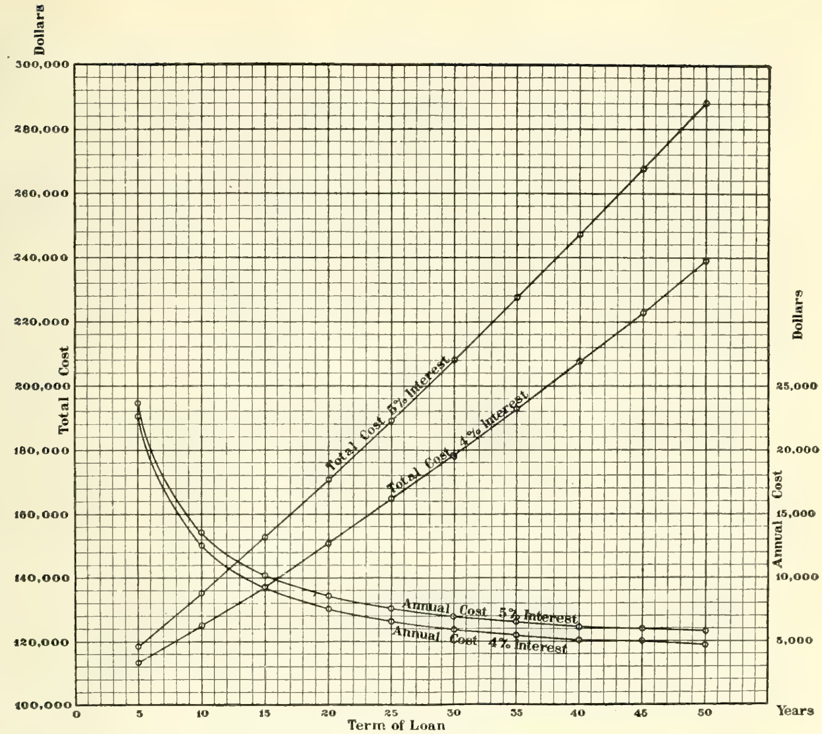


Fig. 1.—Diagram Showing the Relation Between Annual and Total Cost and the Period of Highway Bonds—$100,000 Sinking Fund, 3½ Per Cent.

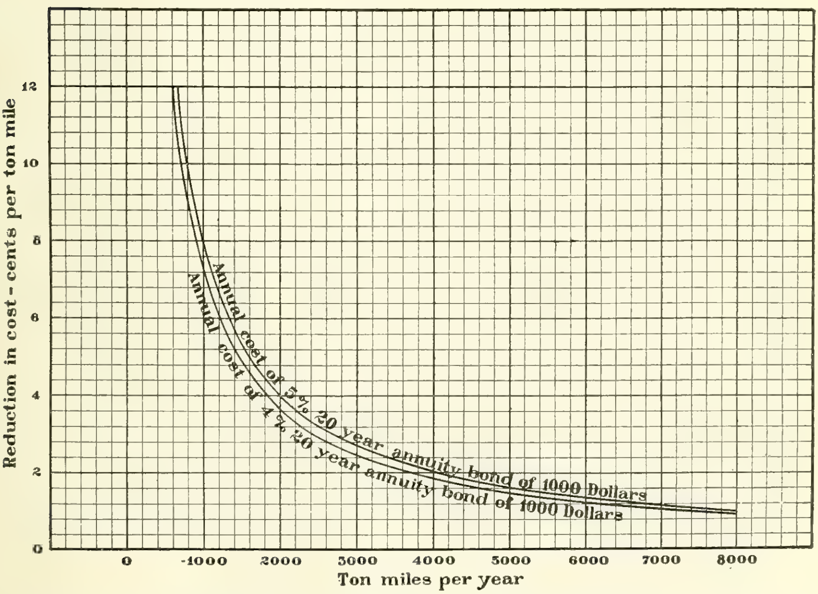


Fig. 2.—Diagram Showing the Relation Between Total Reduction in Cost of Hauling and Annual Cost of a $1,000 Bond.

MAP SHOWING MARKET ROAD SYSTEM, DALLAS COUNTY, ALA.

ing over six market roads assumed uniformly distributed about a market center and extending from 1 to 15 miles through a territory each acre of which yields the same weight of market products.

TABLE 4.—*Theoretical average tonnage on each of six uniformly distributed market roads.*

Maximum haul.	Average haul.	Uniform yield per acre of—								
		One-tenth ton.			One-fourth ton.			One-half ton.		
		Total tons per year.	Tons hauled per day.		Total tons per year.	Tons hauled per day.		Total tons per year.	Tons hauled per day.	
			Over first mile	Over eighth mile.		Over first mile.	Over eighth mile.		Over first mile.	Over eighth mile.
1	0.66	33.5	0.07	....	88.8	0.17	....	167.5	0.34	....
2	1.32	134.0	.40	....	335.0	1.00	....	670.0	2.01	....
3	2.00	301.6	.96	....	754.0	2.40	....	1,508.0	4.80	....
4	2.67	536.2	1.74	....	1,340.5	4.36	....	2,681.0	8.71	....
5	3.33	837.8	2.75	....	2,094.5	6.87	....	4,189.0	13.74	....
6	4.00	1,206.2	3.98	....	3,015.5	9.95	....	6,031.0	19.90	....
7	4.67	1,642.2	5.43	....	4,105.5	13.58	....	8,211.0	27.15	....
8	5.33	2,144.8	7.11	0.85	5,362.0	17.76	2.13	10,724.0	35.52	4.25
9	6.00	2,714.5	9.00	2.75	6,786.3	22.51	6.88	13,572.5	45.02	13.75
10	6.67	3,351.2	11.13	4.87	8,378.0	27.82	12.18	16,756.0	55.63	24.35
11	7.33	4,055.8	13.47	7.22	10,138.5	33.68	18.05	20,279.0	67.35	36.10
12	8.00	4,825.7	16.04	9.79	12,064.3	40.10	24.48	24,128.5	80.20	48.95
13	8.67	5,663.3	18.83	12.58	14,158.2	47.08	31.45	28,316.5	94.15	62.90
14	9.33	6,568.0	21.85	15.59	16,420.0	54.63	38.98	32,840.0	109.25	77.95
15	10.00	7,540.0	25.09	18.83	18,850.0	62.73	47.08	37,700.0	125.45	94.15

The average acreage yield in pounds or the acreage coefficient varies with the locality. As market roads are usually located through farming country, the weight of crops per acre of farm land is a good indication of the tonnage originating on market roads.[1] The report of the 1910 Census shows an approximate average product of 332 pounds per acre of farm land. The average yield per acre on *improved* farm land in crops was 1,674 pounds.[2] The average weight per acre of forest products on unimproved farm land was 122 pounds.[3]

It is found that usually 20 per cent of the roads in any county carry nearly all the traffic—possibly 90 per cent of the total. In the United States 20 per cent of the total mileage of roads is about 440,000 miles. There is an average of about 2,000 acres of *farm* land to each mile of such road, which should represent about 65 per cent[4]

[1] There is a considerable return haul of fertilizer, fuel, kerosene, supplies, wire fence, etc., which can be partially determined by thorough inquiry of dealers.

[2] A careful computation of the weight per acre of all marketed crops in Tompkins County, N. Y., based on the data of Bulletin No. 295 of the Cornell Agricultural Experiment Station, gave 0.51 ton per acre of land in cultivation, which was 70 per cent of the total farm area and 63 per cent of the total area. The acre yield for the entire area was, therefore, 0.35 ton.

[3] These figures are derived by determining the weight and acreage of each crop reported and by making reasonable assumptions as to distribution in the case of fruits, etc., where acreage was not given. (See Table 2.)

[4] The average per cent of lands in farms in 39 States which reported more than 20 per cent of their areas in farms in 1910 was 65.16.

of the adjacent land. On each of the six radial market roads which have been assumed for the calculations above there would be a traffic area of 4,021 acres and a *farm* area of 2,614 acres per mile.

COST OF HIGHWAY CONSTRUCTION.

The cost of a given type of highway varies, but the range of variation has become comparatively well defined for each type within a given region. The standard of construction for any given type is now also generally understood and adhered to in the best practice. As this standard becomes more generally adopted, the price variation for similar local conditions will become less. In Table 5 there are given examples of cost per mile for three types of modern State highways. These averages are taken from lists of State construction jobs which are tabulated in Appendix C.[1] The standard which present specifications represent is a necessary standard evolved as the result of 20 years of modern road building. When these standards are ignored, it is usually at the expense of good work.

TABLE 5.—*Cost elements of three types of highways.*[1]

Type.	Drainage and grading.	Surfacing.	Total.	Drainage and grading.	Surfacing.
				Per cent.	*Per cent.*
Gravel (20 feet wide)	$1,817	$2,599	$4,416	41.15	58.85
Ordinary or water-bound macadam (15 feet wide)	3,400	5,815	9,215	36.90	63.10
Bituminous macadam (15 feet wide)[2]	2,765	7,533	10,298	26.85	73.15

[1] These cost elements were obtained from 87 gravel jobs and 104 macadam jobs in Maine and New Jersey, and from 53 bituminous-macadam jobs in Maine, Massachusetts, and New Jersey. The averages were computed by weighing each job with its relative length and reducing all costs by simple proportion to equivalent average widths of 20 feet and 15 feet respectively. The complete tables of cost elements on the 244 jobs are given in Appendix C.

[2] Includes eight jobs of bituminous resurfacing. (See footnotes, Appendix C.)

The cost of highway construction may be subdivided into (a) cost of enduring features and (b) cost of perishable features. When roads are built with accepted standards of grade, alignment, drainage structures, and foundations, the cost of such elements may be charged for enduring features. Whether roads so built result in the maximum percentage of permanent investment depends in part upon the cost and nature of the wearing surface. For example, a highway completed with all the best enduring features and then surfaced with gravel would show a higher percentage of cost for enduring features than the same road surfaced with more expensive material, as ordinary macadam or bituminous macadam. A poorly constructed gravel road, however, where enduring features had been slighted, would present a very high percentage of charge for temporary features. Macadam roads, so called, have been built with bond money by simply spreading broken stone in the mud. An example is shown in Plate I, figure 2.

[1] These examples were selected from States in which records were kept so as to permit cost analysis.

In issuing bonds for building highways the element of investment is of great importance. The allowable variations in grade and alignment are considerable, as are also the variations in the types of drainage structures. But there exists always a minimum standard below which it is uneconomical for any community to build on borrowed money.

It is manifestly poor policy to build an expensive surface or a relatively long-lived surface on defective grades with poor alignment, or where the drainage features are short-lived and temporary. Construction should be so adjusted to the service needed that its purpose is accomplished without waste. A county with impassable muddy clay roads must obtain, with a bond issue of $100,000, a maximum mileage of improvement. If roads are constructed costing $10,000 per mile, but 10 miles can be built. It is quite probable that the best economic result will be obtained by building 40 miles of road at a cost of $2,500 per mile. This money should be spent largely for enduring features, such as grading, drainage, etc.

The common error, however, in county bond issues is to fix the sum to be voted upon and then to demand an exorbitant mileage for that sum. There is presented in Table 5 and in Appendix C the percentage of the cost of drainage and grading, exclusive of surfacing, and the percentage of cost of the surfacing on a considerable mileage of road from several States.

Not all the surfacing need be a perishable feature. It is becoming more and more common to construct roads with surfaces built in two courses, the lower of which is regarded as a permanent feature of construction. This is particularly true of those types of road that are built with concrete foundations for bituminous-macadam, brick, or asphalt surfaces. Most hard roads are now seldom allowed to wear into the foundation course of the surfacing. It is probably conservative to regard 40 per cent of the surfacing cost of macadam or more enduring pavements as a cost for permanent features. Well-built macadam roads, from the recorded costs in Table 5, would therefore indicate a cost of 62 per cent of the total cost for permanent features and bituminous-macadam roads about 56 per cent. This method of estimating can not be applied to gravel or any natural soil road. Under most existing systems of maintenance the entire surfacing of such roads steadily deteriorates. It is generally accepted that roads built with surfaces entirely of concrete or with a brick pavement and a concrete foundation are permanent. It is not, however, yet known how long the best concrete surface will wear and it is certain that serious failures of concrete surfaces have resulted from poor construction. The best vitrified brick surfaces may have a life of 30 years or more, but repairs will usually be required and sufficiently extensive data on the life of modern vitrified brick roads grouted with cement mortar are still lacking to fix the average life period.[1]

The danger of building roads with little attention to anything but the surface, with no provision for repair and maintenance, and with bonds of excessive term is, however, very serious. Complete returns of highway mileage built with local bond issues are not available, but there is given in Appendix B (Tables 25 and 26) a list of bond issues and mileage constructed with the proceeds where the reports are complete.

COST OF HIGHWAY MAINTENANCE.

Highways constructed with borrowed money should be strictly maintained.[2] Maintenance is necessary in order to insure to the community the maximum economic service by the road and also to preserve the investment. The cost of maintenance and repairs must, therefore, be studied at the outset. Unfortunately public records do not yet present complete data on the cost of either repair or maintenance, except in certain States which have highway departments.

Well-constructed gravel roads will sometimes sustain several years of traffic without showing marked deterioration, even when there has been no maintenance. Such roads sometimes even improve during the second season; more frequently, however, they show ruts or the formation of chuck holes. It can not be expected that the average life of a gravel surface will be greater than that of a macadam surface. The average interval for resurfacing macadam roads is between six and seven years. If a sum equal to two-thirds of the original cost of the gravel surface itself is provided for renewals at six-year intervals, it should be estimated at from $150 to $250 per mile per year. If $30 is then allowed for annual dragging and small repairs, the total annual cost of repair and maintenance of gravel roads would be from $180 to $280 per mile. The annual cost of strict maintenance is sometimes below $30. In Bennington County, Vt., during 1912, 175 miles of gravel roads were maintained at a cost of $20.70 per mile. The annual cost of maintenance and repair on sand-clay roads, including all necessary resurfacing at periodic intervals, should not be fixed at less than 10 per cent of the original cost.

The cost of repair and maintenance of water-bound macadam roads has been determined with considerable exactness from Massachusetts figures and checked by resurfacing charges in other States and in Germany. From $100 to $125 per year ordinarily pays for necessary small repairs, such as patching, cleaning culverts, etc.,

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[1] For further information as to the life of roads, see Bulletin No. 48 of the Office of Public Roads, U. S. Department of Agriculture, "Repair and Maintenance of Highways," and Bulletin No. 23 of the U. S. Department of Agriculture, "Vitrified Brick as a Paving Material for Country Roads." These bulletins may be obtained from the U. S. Department of Agriculture.

[2] See Bulletin 48, Office of Public Roads, U. S. Department of Agriculture.

and from \$400 to \$425 per year is the necessary annual charge for resurfacing at periods varying from six to seven years. (See footnote 1, p. 12.) The sum of \$525 per mile, on an average, should therefore absolutely maintain macadam roads if changes and increases of traffic are not excessive. It must be understood, however, that in many instances where macadam sufficed for the volume and character of traffic prior to 1906, it will not withstand the action of the motor vehicle traffic which has developed since that time.

Many miles of ordinary or water-bound macadam road have been resurfaced with bituminous materials and many miles of new bituminous-macadam road have been constructed. The logical maintenance of such highways is a surface treatment with bituminous material and rock screenings, clean gravel, or sharp sand. The cost of such surface treatment is from 4 to 12 cents per square yard, and it may be expected to last from one to three years, according to the density of traffic and the success of the application. Theoretically, perfect surface treatment would constitute absolute maintenance for a bituminous-macadam road. Such maintenance is seldom or never realized and bituminous-macadam roads doubtless require resurfacing at intervals. The cost of such resurfacing is not yet known. The average cost for repair and maintenance of 7,300 miles of highway in Connecticut, Massachusetts, New York, New Jersey, and Rhode Island for the year 1912 was about \$800 per mile. A large part of this money was expended for bituminous resurfacing and bituminous surface treatment. There is some question whether the expenditure correctly measures the average cost of repairing and maintaining bituminous-macadam roads. In the State of New York, however, for the years 1911 and 1912 the average cost for repair and maintenance was \$724 per mile upon a total average of 2,861 miles. The annual cost of repair and maintenance on Massachusetts State roads for the years 1910, 1911, and 1912 was, respectively, \$642, \$647, and \$676 per mile for about 850 miles. For the most part these figures for New York and Massachusetts represent the cost per mile of resurfacing with bituminous material and of maintaining bituminous-macadam and water-bound macadam roads by surface treatment with bituminous material. It is clear, therefore, that \$700 per mile is not an excessive estimate at present for the annual cost of all repair and maintenance of bituminous-macadam roads.

The cost of maintaining concrete roads is not yet known. It is known, however, that great care must be exercised in constructing such roads to insure their success. There have been cases where such roads began to disintegrate along the wheel tracks in less than a year, owing to defective concrete. Sometimes such roads have cracked so badly that it was necessary to remove the surface entirely. In other instances the necessary repairs have been very expensive.

Instances are also known where concrete road surfaces have shown a very high percentage of annual wear. In other cases there is apparently no measurable wear. If the road surface is built with the proper mix of concrete and carefully placed, it apparently should last indefinitely and not rut. Some cleaning of the surface and patching of joints and small depressions will be necessary at all times, so that the maintenance can not be entirely neglected.

The cost of repair and maintenance upon brick highways is very low. In most instances, where the construction is as nearly perfect as possible, almost no maintenance charges have resulted. Perfect construction, however, is seldom obtained.[1] It is not unusual to find depressions and points of wear in brick roads, but it is less common than formerly. Brick roads are now usually constructed on a concrete foundation, with very carefully selected vitrified brick, and with the joints filled with cement mortar. Their annual maintenance costs, although low, are not on record with sufficient continuity to supply accurate data.

It has not been customary for officials to face frankly the cost of maintenance and repair on bond-built highways at the time the bonds are issued and before construction begins. In fact, in the majority of cases where bonds have been issued by local authorities there has been no provision whatever for maintaining the roads when built. This is perhaps the gravest defect in the project of building highways by issuing bonds. The cost of all maintenance and repair over a series of years has ranged in the past from 6 to 10 per cent of the original cost of construction on the average and varies with the type of construction. Concrete roads and brick roads apparently are a marked exception to this rule. In future construction where the type of road is properly adapted to traffic and with careful maintenance from the outset the percentage of repair and maintenance cost should be lower.

THE BOND ISSUE.

Sinking-fund bonds.—The majority of highway bonds now outstanding have been issued as straight terminable bonds to be retired by sinking funds. Many such bonds now run for excessive terms. Although the term varies from 10 to 40 years, the average is nearly 25 years.[2] The fund to retire the bonds is accumulated by annual installments paid by the taxpayers and is supposed to draw interest continuously and to accumulate a sufficient amount to discharge the debt at maturity. The interest which the sinking fund draws is usually from 1 to 2 per cent less than the interest paid for the loan. Five per cent highway bonds are common with the sinking fund calculated to draw $3\frac{1}{2}$ per cent interest. Table 6 shows the annual payments to the sinking fund necessary to accumulate $1,000

[1] Cf. Bulletin 23 of the U. S. Department of Agriculture.
[2] Some issues—notably New York State—run 50 years. Cf. Appendices A and B.

at 3, 3½, and 4 per cent compounded semiannually for varying periods from 1 to 30 years.

TABLE 6.—*Annual payments which, with interest at 3, 3½, and 4 per cent, compounded semianually, will amount to $1,000 at the end of a term of years.*[1]

Years.	Annual payments.			Years.	Annual payments.		
	3 per cent.	3½ per cent.	4 per cent.		3 per cent.	3½ per cent.	4 per cent.
1	$1,000.0000	$1,000.0000	$1,000.0000	16	$49.5229	$47.5689	$45.6734
2	492.5562	491.3266	490.1000	17	45.8652	43.9283	42.0537
3	323.4583	321.8368	320.2221	18	42.6221	40.7032	38.8504
4	238.9468	237.1428	235.3498	19	39.7280	37.8279	35.9976
5	188.2699	186.3672	184.4796	20	37.1306	35.2499	33.4426
6	154.5102	152.5508	150.6104	21	34.7875	32.9267	31.1429
7	130.4175	128.4252	126.4560	22	32.6639	30.8236	29.0636
8	112.3666	110.3564	108.3733	23	30.7313	28.9116	27.1759
9	98.3436	96.3254	94.3382	24	28.9656	27.1670	25.4557
10	87.1402	85.1208	83.1366	25	27.3469	25.5696	23.8829
11	77.9872	75.9717	73.9954	26	25.8582	24.1024	22.4404
12	70.3721	68.3643	66.3996	27	24.4850	22.7508	21.1136
13	63.9399	61.9427	59.9924	28	23.2149	21.5024	19.8901
14	58.4372	56.4527	54.5191	29	22.0373	20.3465	18.7591
15	53.6780	51.7080	49.7928	30	20.9428	19.2739	17.7113

[1] In Appendix D, page 98, Example 9 shows the method of calculating this table.

Table 7 illustrates how an annual sinking fund of $32,345.83 accumulates for three years to $100,000.

TABLE 7.—*Accumulations of an annual payment of $32,345.83 with interest at 3 per cent compounded semiannually.*

Number of 6-month intervals.	Principal at beginning of 6-month intervals.	Interest during 6-month intervals.	Annual payment at end of 6-month intervals.	Total amount at end of 6-month intervals.
1	$0.00	$0.00	$0.00	$0.00
2	0.00	0.00	32,345.83	32,345.83
3	32,345.83	485.19	0.00	32,831.02
4	32,831.02	492.47	32,345.83	65,669.32
5	65,669.32	985.04	0.00	66,654.36
6	66,654.36	999.81	32,345.83	100,000.00

To obtain the necessary annual payments to produce any multiple of $1 it is necessary merely to multiply the tabular value in Table 6 by the corresponding multiple; thus, an annual sinking fund payment to retire $100,000 in 15 years at 3½ per cent would be $5,170.80. Table 33, pages 120 and 121, gives the yearly or periodic payments necessary to accumulate $1 in a given number of years or periods at varying rates of interest.

There are objections to the sinking-fund method of retiring highway bonds. It may not be possible to obtain continuously the requisite rate of interest on the sinking fund to discharge the debt at maturity. The existence of the sinking fund is a constant temptation to municipal officers to use it for purposes other than the purpose originally intended. If a county, for example, issues bonds for a second object, it is easy to argue that the sinking fund already accumulated may be used to purchase the new securities, and the finances of the community are in a way to become much confused. This is particularly true since the officers in charge of such operations are frequently changing. Sinking fund tax levies may be deferred through carelessness or under pressure of other needs. The sinking fund always requires careful attention, because it does not progress automatically in most cases.[1] It has sometimes been entirely neglected. The total cost of a bond issue retired by a sinking fund will be greater in the end than the cost of the same bond issue made by either the annuity method or by the serial method.

Annuity bonds.—By the annuity method of issuing bonds both the principal and interest are discharged by constant annual or semiannual payments. The amount of each payment or installment is determined by the rate of interest and the term of the bond. It usually is necessary to subdivide the bond issue into individual bonds of $100, $500, or $1,000 each. The resulting periodic payment of principal and interest must vary slightly because of this adjustment. Tables 8 and 9 show, in detail, the schedule of principal and interest repayments upon a loan of $100,000 for 20 years, retired by this plan at 4 and 5 per cent per annum, respectively. The necessary adjustment to the nearest $100 bond is also shown. It will be seen that the amount of principal retired is small at first and constantly increases while the interest charge decreases. The sum of interest and principal remains constant, and this is an advantage as the tax is then uniform.

TABLE 8.—*Repayment of a 4 per cent $100,000 loan, including both principal and interest, by a uniform annual payment of $7,358.175 for 20 years.*[2]

	Adjusted to nearest cent.			Adjusted to $100 bonds.			
Years.	Principal owing at beginning of year.	Interest for year.	Principal repaid at end of year.	Principal owing at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.
1	$100,000.00	$4,000.00	$3,358.18	$100,000	$4,000	$3,400	$7,400
2	96,641.82	3,865.67	3,492.50	96,600	3,864	3,500	7,364
3	93,149.32	3,725.97	3,632.21	93,100	3,724	3,600	7,324
4	89,517.11	3,580.68	3,777.49	89,500	3,580	3,800	7,380
5	85,739.62	3,429.59	3,928.59	85,700	3,428	3,900	7,328
6	81,811.03	3,272.44	4,085.73	81,800	3,272	4,100	7,372
7	77,725.30	3,109.01	4,249.17	77,700	3,108	4,200	7,308
8	73,476.13	2,939.05	4,419.12	73,500	2,940	4,400	7,340
9	69,057.01	2,762.28	4,595.90	69,100	2,764	4,600	7,364
10	64,461.11	2,578.44	4,779.73	64,500	2,580	4,800	7,380
11	59,681.38	2,387.26	4,970.92	59,700	2,388	5,000	7,388
12	54,710.46	2,188.42	5,169.75	54,700	2,188	5,200	7,388
13	49,540.71	1,981.63	5,376.55	49,500	1,980	5,400	7,380
14	44,164.16	1,766.57	5,591.60	44,100	1,764	5,600	7,364
15	38,572.56	1,542.90	5,815.28	38,500	1,540	5,800	7,340
16	32,757.28	1,310.29	6,047.88	32,700	1,308	6,000	7,308
17	26,709.40	1,068.38	6,289.80	26,700	1,068	6,300	7,368
18	20,419.60	816.78	6,541.39	20,400	816	6,500	7,316
19	13,878.21	555.13	6,803.05	13,900	556	6,800	7,356
20	7,075.16	283.01	7,075.16	7,100	284	7,100	7,384
Totals		47,163.50	100,000.00		47,152	100,000	147,152

[1] In some States there are restrictions on the nature of county investments for sinking fund purposes.

[2] An additional table showing the annual payments necessary to discharge a loan of $1, with interest for varying terms and rates, is given in Table 36 on pages 126 and 127.

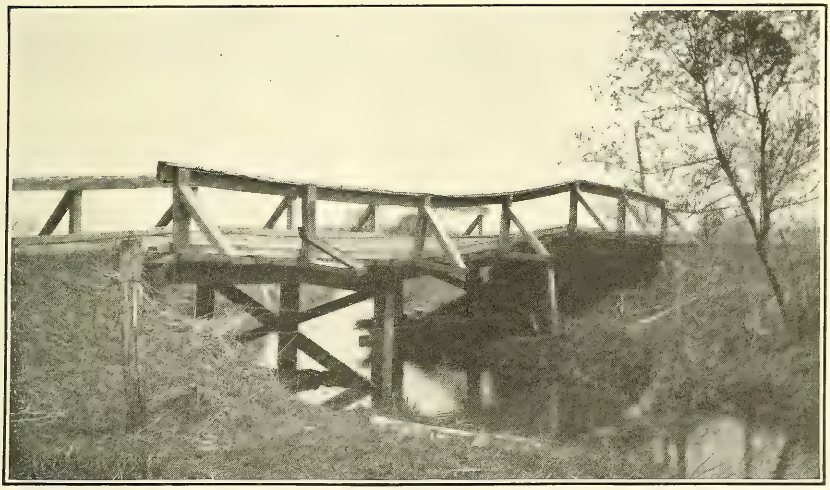


FIG. 1.—DALLAS COUNTY, ALA. WOODEN BRIDGE ON AN UNIMPROVED ROAD, 1 MILE NORTHWEST OF MARION JUNCTION.

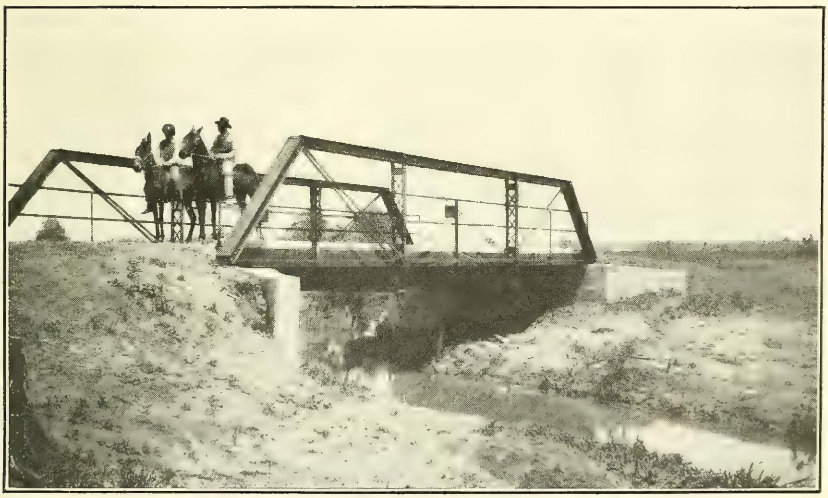
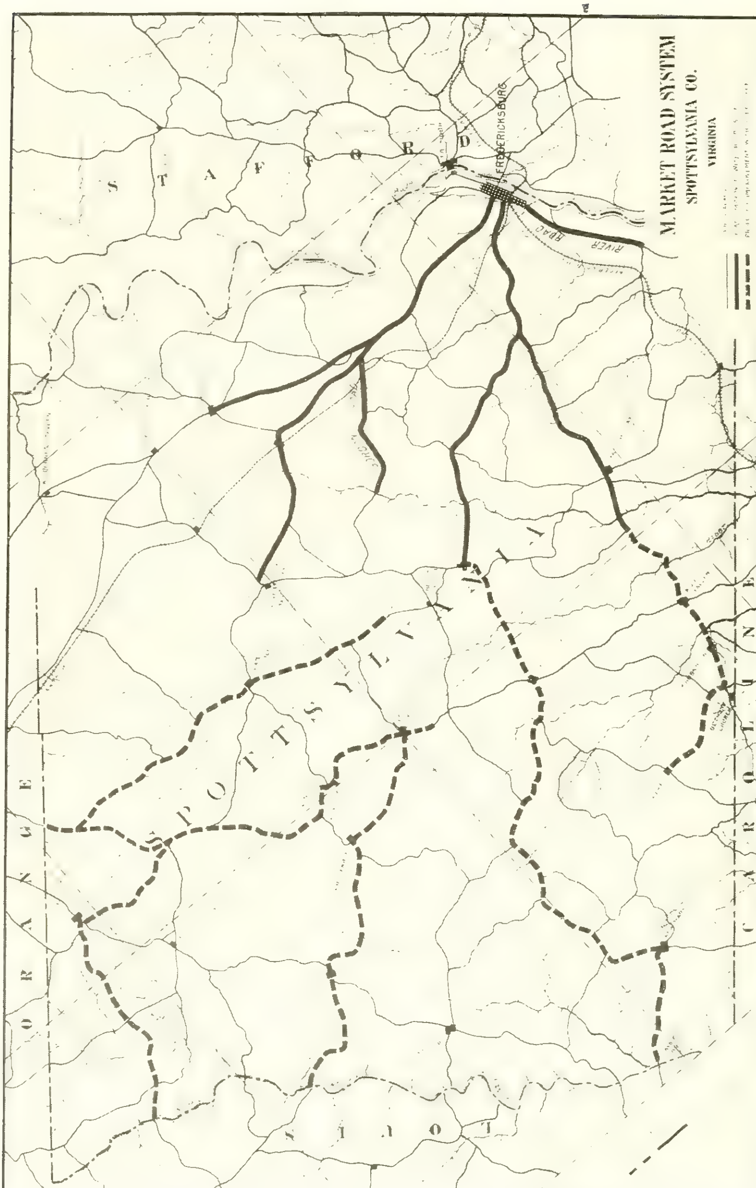


FIG. 2.—DALLAS COUNTY, ALA. NEW STEEL BRIDGE WITH CONCRETE FLOOR BUILT IN 1911 TO REPLACE THE BRIDGE IN FIGURE 1.



MAP SHOWING MARKET ROAD SYSTEM, SPOTSYLVANIA COUNTY, VA.

FIG. 1.—SPOTSYLVANIA COUNTY, VA. UNIMPROVED ROAD FROM FREDERICKSBURG TO CHANCELLORSVILLE, MARCH, 1910.

FIG. 2.—SPOTSYLVANIA COUNTY, VA. CHANCELLORSVILLE ROAD IMPROVED, MARCH, 1911.

FIG. 1.—LEE COUNTY, VA. ONE AND ONE-HALF MILES FROM JONESVILLE; NEW MACADAM ROAD BUILT FROM BOND ISSUE; OLD ROAD SHOWN AT THE RIGHT FOREGROUND.

FIG. 2.—LEE COUNTY, VA. IMPROVED ROAD BUILT UNDER BOND ISSUE OF 1911 NEAR CUMBERLAND GAP; OLD ROAD IS SHOWN AT THE RIGHT.

Map Showing Improved Roads, Wayne County, Mich.

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TABLE 9.—*Repayment of a 5 per cent $100,000 loan, including both principal and interest, by a uniform annual payment of $8,024.259[1] for 20 years.*

	Adjusted to nearest cent.			Adjusted to $100 bonds.			
Years.	Principal owing at beginning of year.	Interest for year.	Principal repaid at end of year.	Principal owing at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.
1	$100,000.00	$5,000.00	$3,024.25	$100,000	$5,000	$3,000	$8,000
2	96,975.75	4,848.79	3,175.47	97,000	4,850	3,200	8,050
3	93,800.28	4,690.02	3,334.24	93,800	4,690	3,300	7,990
4	90,466.04	4,523.30	3,500.96	90,500	4,525	3,500	8,025
5	86,965.08	4,348.25	3,676.01	87,000	4,350	3,700	8,050
6	83,289.07	4,164.45	3,859.81	83,300	4,165	3,900	8,065
7	79,429.26	3,971.46	4,052.80	79,400	3,970	4,100	8,070
8	75,376.46	3,768.82	4,255.44	75,300	3,765	4,300	8,065
9	71,121.02	3,556.05	4,468.21	71,000	3,550	4,500	8,050
10	66,652.81	3,332.64	4,691.62	66,500	3,325	4,700	8,025
11	61,961.19	3,098.06	4,926.19	61,800	3,090	4,900	7,990
12	57,035.00	2,851.75	5,172.51	56,900	2,845	5,200	8,045
13	51,862.49	2,593.13	5,431.13	51,700	2,585	5,400	7,985
14	46,431.36	2,321.57	5,702.69	46,300	2,315	5,700	8,015
15	40,728.67	2,036.43	5,987.83	40,600	2,030	6,000	8,030
16	34,740.84	1,737.04	6,287.22	34,600	1,730	6,300	8,030
17	28,453.62	1,422.68	6,601.58	28,300	1,415	6,600	8,015
18	21,852.04	1,092.60	6,931.66	21,700	1,085	6,900	7,985
19	14,920.38	746.02	7,278.24	14,800	740	7,200	7,940
20	7,642.14	382.12	7,642.14	7,600	380	7,600	7,980
Totals	....	60,485.18	100,000.00	....	60,405	100,000	160,405

[1] Cf. Example 14, p. 101, for details of calculations.

Serial bonds.—The serial bond differs somewhat from the annuity bond, because, instead of keeping the annual payment of both principal and interest constant, the principal alone retired each year remains fixed. This type of bond has become more common for highway purposes in recent years, and during 1912 and 1913 the number of serial issues exceeded the number of issues for any other single given term. The Office of Public Roads received reports for these two years of $15,300,819 in serial highway bonds, which is over 20 per cent of the total county and district bonds for which the period or term of issue was reported. In Tables 10 and 11 are given the necessary annual payments of interest and principal for an issue of $100,000 for 20 years at 4 and 5 per cent, respectively, where the bonds are retired by annual payments of $5,000 each. The first retirement is sometimes deferred for a number of years.

TABLE 10.—*Schedule of interest and principal to retire a serial loan of $100,000 at 4 per cent, with annual principal repayments of $5,000.*

Years.	Principal outstanding at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.	Years.	Principal outstanding at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.
1	$100,000	$4,000	$5,000	$9,000	12	$45,000	$1,800	$5,000	$6,800
2	95,000	3,800	5,000	8,800	13	40,000	1,600	5,000	6,600
3	90,000	3,600	5,000	8,600	14	35,000	1,400	5,000	6,400
4	85,000	3,400	5,000	8,400	15	30,000	1,200	5,000	6,200
5	80,000	3,200	5,000	8,200	16	25,000	1,000	5,000	6,000
6	75,000	3,000	5,000	8,000	17	20,000	800	5,000	5,800
7	70,000	2,800	5,000	7,800	18	15,000	600	5,000	5,600
8	65,000	2,600	5,000	7,600	19	10,000	400	5,000	5,400
9	60,000	2,400	5,000	7,400	20	5,000	200	5,000	5,200
10	55,000	2,200	5,000	7,200					
11	50,000	2,000	5,000	7,000	Totals.	....	42,000	100,000	142,000

TABLE 11.—*Schedule of interest and principal to retire a serial loan of $100,000 at 5 per cent, with annual principal repayments of $5,000.*

Years.	Principal outstanding at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.	Years.	Principal outstanding at beginning of year.	Interest for year.	Principal repaid at end of year.	Total.
1	$100,000	$5,000	$5,000	$10,000	12	$45,000	$2,250	$5,000	$7,250
2	95,000	4,750	5,000	9,750	13	40,000	2,000	5,000	7,000
3	90,000	4,500	5,000	9,500	14	35,000	1,750	5,000	6,750
4	85,000	4,250	5,000	9,250	15	30,000	1,500	5,000	6,500
5	80,000	4,000	5,000	9,000	16	25,000	1,250	5,000	6,250
6	75,000	3,750	5,000	8,750	17	20,000	1,000	5,000	6,000
7	70,000	3,500	5,000	8,500	18	15,000	750	5,000	5,750
8	65,000	3,250	5,000	8,250	19	10,000	500	5,000	5,500
9	60,000	3,000	5,000	8,000	20	5,000	250	5,000	5,250
10	55,000	2,750	5,000	7,750					
11	50,000	2,500	5,000	7,500	Totals.	....	52,500	100,000	152,500

Comparison of serial, annuity, and sinking-fund bonds.—It will be noticed that the total expense to the community under the serial plan is somewhat less than under the annuity plan. The expense by either method is, however, considerably less than the expense under the sinking-fund plan. For the purpose of comparison the total expense to the community under each plan is assembled under Table 12.

Tables 8 to 11, inclusive, are computed with interest payable annually. Bonds with interest payable semiannually sell better. Similar tables or schedules for the annuity and serial plans of bond issues to conform to semiannual interest payments can be easily prepared. Schedules can also be prepared to show the progress of a bond loan when the bonds are bought at a premium or discount.[1]

TABLE 12.—*Total cost of a loan of $100,000 for 20 years, interest compounded annually.*

Annual interest on bonds.	Sinking fund compounded annually at— 3 per cent.	3½ per cent.	4 per cent.	Annuity.	Serial.
4	$154,431	$150,722	$147,163	$147,163	$142,000
4½	164,431	160,722	157,163	153,752	147,250
5	174,431	170,722	167,163	160,485	152,500
5½	184,431	180,722	177,163	167,359	157,750
6	194,431	190,722	187,163	174,369	163,000

In a bond issue by any given plan the amount, the interest, and the term may be fixed at will, but when this is done the annual repayments of principal and interest are theoretically determined. Thus, by the annuity method, if $100,000 is to be issued at 5 per cent annually and retired in 20 years, the annual amount of interest and principal is at once determined to be approximately $8,000.

[1] Cf. Appendix D, pages 91 to 115, for details of such schedules.

For the same bond issue under the serial plan, the total annual payment varies because the interest varies, but each yearly payment of interest and principal is nevertheless fixed.

Under the sinking-fund plan the annual payment necessary for principal and interest is theoretically constant, but it depends upon the interest realized upon the sinking fund. It is not safe, as a rule, to estimate this interest at more than 3½ per cent. Then for a $100,000 20-year loan, with annual interest on the sinking fund, the total annual payment would be $8,536.11. If the sinking fund could earn the rate of interest which is paid upon the loan there would be no advantage in expense to the community in the annuity or the serial bond over the sinking-fund bond. There is given in Table 13 the total mill tax on $1 to retire a bond issue of $100,000 by the sinking fund or the annuity plan.

TABLE 13.—*Annual mill tax on $1 for interest and retirement on a bond issue of $100,000, at 5 per cent annual interest, for terms of 10 and 20 years.*

Valuation.	Mill tax.							
	10 years.				20 years.			
	Sinking-fund plan.[1]			Annuity plan.[2]	Sinking-fund plan.[1]			Annuity plan.[2]
	3 per cent.	3½ per cent.	4 per cent.		3 per cent.	3½ per cent.	4 per cent.	
$1,000,000	13.723	13.524	13.329	12.950	8.722	8.536	8.358	8.024
1,500,000	9.149	9.016	8.886	8.634	5.814	5.691	5.572	5.350
2,000,000	6.861	6.762	6.665	6.475	4.361	4.268	4.179	4.012
2,500,000	5.489	5.410	5.332	5.180	3.489	3.414	3.343	3.210
3,000,000	4.574	4.508	4.443	4.317	2.907	2.845	2.786	2.675
3,500,000	3.921	3.864	3.808	3.700	2.492	2.439	2.388	2.293
4,000,000	3.431	3.381	3.332	3.238	2.180	2.134	2.090	2.006
4,500,000	3.050	3.005	2.962	2.878	1.938	1.897	1.857	1.783
5,000,000	2.745	2.705	2.666	2.590	1.744	1.707	1.672	1.605
5,500,000	2.495	2.459	2.423	2.355	1.586	1.552	1.520	1.459
6,000,000	2.287	2.254	2.222	2.158	1.454	1.423	1.393	1.337
6,500,000	2.111	2.081	2.051	1.992	1.342	1.313	1.286	1.235
7,000,000	1.960	1.932	1.904	1.850	1.246	1.219	1.194	1.146
7,500,000	1.830	1.803	1.777	1.727	1.163	1.138	1.114	1.070
8,000,000	1.715	1.691	1.666	1.619	1.090	1.067	1.045	1.003
8,500,000	1.614	1.591	1.568	1.524	1.026	1.004	.983	.944
9,000,000	1.525	1.503	1.481	1.439	.969	.948	.929	.892
9,500,000	1.445	1.424	1.403	1.363	.918	.899	.880	.845
10.000,000	1.372	1.352	1.333	1.295	.872	.854	.836	.802

[1] With interest compounded annually.
[2] The tax for the serial plan is slightly less, but varies from year to year.

It is quite probable that so many 30-year bonds are issued in order to take advantage of the fact that bonds of that term result in a low annual charge for interest and sinking fund. It will be seen from Table 14 that very little advantage is gained by fixing the term of a bond longer than 30 years. The annual charge decreases very slowly from that point, whereas the total charge increases rapidly.

TABLE 14.—*Annual and total costs of a loan of $100,000 for varying periods, with sinking fund to draw 3½ per cent interest, compounded annually.*

Term in years.	Annual interest on bonds.			
	4 per cent.		5 per cent.	
	Total annual payment, interest, and sinking fund.	Total cost of loan.	Total annual payment, interest, and sinking fund.	Total cost of loan.
5	$22,648	$113,241	$23,648	$118,241
10	12,524	125,241	13,524	135,241
15	9,183	137,738	10,183	152,738
20	7,536	150,722	8,536	170,722
25	6,567	164,185	7,567	189,185
30	5,937	178,114	6,937	208,114
35	5,500	192,494	6,500	227,494
40	5,183	207,309	6,183	247,309
45	4,945	222,540	5,945	267,540
50	4,763	238,169	5,763	288,169

The same facts are presented in the diagram of Plate III, figure 1. The curves of annual cost of interest and retirement fall very slowly after the 30-year point.

It is an unfortunate fact that most highways do not have a life of 30 years, and it is now quite evident that the life of the highway and not the apparent economic term of the bond should determine the length of the loan. Many miles of natural soil roads are annually built by 30-year bond issues. There is usually no provision for repair and maintenance charges, and little business organization in the county road system. This practice is financially dangerous. No gravel road surface can last 30 years,[1] and apparently the only road surfaces for which a 30-year life is recorded are surfaces of far more expensive construction than are usually built under the bond issues reported to the Office of Public Roads.

There is a further advantage in the annuity or serial bond for highway construction, because it is more likely under such a bond that the road surface will be paid for before it is entirely worn out. If an annuity or serial bond begins to mature immediately, this is not considered a serious objection among bankers. These types of bonds are particularly adapted for financing operations which by their very nature involve a wasting of the property. A highway is in part a wasting property and it is desirable to have established a margin of safety in highway financing. Railroads frequently issue serial equipment bonds for a period of 10 years with which to purchase rolling stock. The amount of bonds retired annually is carefully adjusted so that the retirement is faster than the depreciation of the rolling stock. The difference between the outstanding bonds and the value of the equipment in any year is the margin of safety.

[1] Massachusetts in 1912 reduced the term of State highway bonds from 30 to 15 years. Wisconsin passed a law, effective in 1913, providing that counties may issue 5 per cent bonds for State highways for periods not to exceed 10 years. The bonds must be serial bonds, with interest and redemption fund to be raised by direct taxation.

From the nature of the annuity or the serial form of highway bonds it is never necessary to issue new or refunding bonds at the end of the term. Both of these types of bonds have the advantage that they accomplish with one financial operation all that the sinking-fund type of bond can accomplish. The main advantage, however, of both types of bonds is that the community saves more money than under the sinking-fund plan because it avoids paying a higher rate on borrowed money than it can obtain on money that it loans.

Highway bonds are seldom sold at par. Not infrequently they command a slight premium; that is to say, they are sold at an advance over the par value. In nearly every State the law provides that municipal bonds shall not be sold at less than par.[1] When the purchaser pays a premium for a 5 per cent highway bond it will yield less than 5 per cent. To enable investors to determine quickly the net rate of yield from a bond purchased at a premium or at a discount, tables known as bond tables have been calculated. In Appendix D is presented a short bond table of this kind (Table 37). From this table the net yield of a bond with a nominal rate of interest of from 3 to 6 per cent, payable semiannually and for varying terms, may be calculated for various prices. Thus a 5 per cent 15-year highway bond purchased at 103.20, or with a premium of 3.20 per cent, will be found to yield the purchaser 4.70 per cent on his investment.[2] Such tables are of more important interest to the purchaser than to the municipality offering the bonds, but they are necessary for the intelligent direction of the bond issue.

In calculating the price to be paid for serial bonds, it is customary to treat each series separately and to find the price that yields the given net rate by adding the separate prices. Some formulas will be found, however, in Appendix D which considerably shorten the labor of calculating the price to be paid for serial bonds and the labor of related calculations.

Special form of annuity bond.—In the operation of the annuity bond both interest and principal are discharged by a series of equal installments, usually semiannual. Each installment contains interest on the bonds outstanding at the beginning of the interval and the balance is applied to retire the bonds. The effect of this method is to diminish steadily the investment of the purchaser. If, however, the borrower should arrange to set aside periodically in a sinking fund a fixed sum *in excess of the periodic interest on the entire issue,* the effect would be to leave the total investment of the purchaser undisturbed until the sinking fund had accumulated to the amount of the loan. When the excess of the periodic installment over the required interest is arbitrarily selected and accumulates at a given rate of

[1] Massachusetts requires the premium to be deposited in the sinking fund. To avoid paying par value for the bonds, bidders frequently bid par or above par and require an allowance for attorney's fees and expenses.

[2] Cf. Appendix D, page 129.

interest, the term of the bond is thereby absolutely fixed. A simple way to accomplish this result is to add to the nominal interest rate which the bonds pay a percentage of the principal to be set aside in a sinking fund to retire the bonds. There is produced thus a new nominal rate. Since both interest and principal are discharged by the periodical payment of interest or dividends at the new nominal rate, an issue of this character may be described as a special form of annuity bond.

Table 15 shows the resulting terms in years of a bond issue for $1,000,000 where from 1½ to one-half per cent of the principal is set aside semiannually in a sinking fund which draws 3 per cent compounded semiannually. The original interest rate on the bonds is assumed to be 3 per cent, payable semiannually, and the new increased nominal rate varies then from 6 to 4 per cent. The last column shows the total cost to the borrower for the loan of $1,000,000 under this method.

TABLE 15.—*Necessary terms and total costs of a bond issue of $1,000,000 at 3 per cent, payable semiannually, when retired by various arbitrary fractions of the principal set aside and compounded semiannually.*

Applied semiannually to sinking fund to retire bond issue.	New increased interest rate on original 3% bonds.	Term of bonds.	Total cost to borrower.
Per cent. of loan.	*Per cent.*	*Years.*	*Dollars.*
1½	6	23½	1,410,000
1⅜	5¾	25	1,437,500
1¼	5½	26½	1,457,500
1⅛	5¼	28½	1,496,250
1	5	31	1,550,000
⅞	4¾	34	1,615,000
¾	4½	37	1,665,000
⅝	4¼	41½	1,763,750
½	4	47	1,880,000
½	4	50	2,000,000

The progress of the accumulation of the semiannual sinking fund under the plan here outlined is shown for varying retirement rates in Table 17. It is possible so to determine the rate of retirement that the resulting term of the bonds is integral instead of fractional. The increased nominal rates for 3 per cent bonds to retire in varying integral terms is as follows:[1]

TABLE 16.—*Equivalent nominal rates for retiring 3 per cent bonds in varying terms.*

	Per cent.		Per cent.
10 years	11.649148	30 years	5.078686
20 years	6.685420	40 years	4.309664
25 years	5.714336	50 years	3.874114

[1] This rate per cent is determined by the formula:

$$\text{Rate per cent}=3+200/S_{\overline{2n}|}$$

where n is the number of years $S_{\overline{2n}|}$ is determined from Table 32, Appendix D, at the rate 1½%.

TABLE 17.—*Accumulations at 3 per cent, convertible semiannually, of a semiannual sinking fund to extinguish a loan of $1,000,000.*

New increased nominal rate on original 3% bonds.	4 per cent.	4¼ per cent.	4½ per cent.	4¾ per cent.	5 per cent.	5¼ per cent.	5½ per cent.	5¾ per cent.	6 per cent.
	Percentage which the semiannual sinking-fund payment bears to the loan.								
Years.	½ per cent.	⅝ per cent.	¾ per cent.	⅞ per cent.	1 per cent.	1⅛ per cent.	1¼ per cent.	1⅜ per cent.	1½ per cent.
0.5	$5,000.00	$6,250.00	$7,500.00	$8,750.00	$10,000.00	$11,250.00	$12,500.00	$13,750.00	$15,000.00
1.0	10,075.00	12,593.75	15,112.50	17,631.25	20,150.00	22,668.75	25,187.50	27,706.25	30,225.00
1.5	15,226.13	19,032.66	22,839.19	26,645.72	30,452.25	34,258.78	38,065.31	41,871.84	45,678.38
2.0	20,454.52	25,568.15	30,681.78	35,795.40	40,909.03	46,022.66	51,136.29	56,249.92	61,363.55
5.0	53,513.61	66,892.01	80,270.41	93,648.81	107,027.22	120,405.62	133,784.02	147,162.42	160,540.83
10.0	115,618.34	144,522.92	173,427.50	202,332.09	231,236.67	260,141.25	289,045.84	317,950.42	346,855.01
15.0	187,693.41	234,616.76	281,540.11	328,463.46	375,386.81	422,310.17	469,233.52	516,156.87	563,080.22
20.0	271,339.47	339,174.34	407,009.20	474,844.07	542,678.94	610,513.81	678,348.67	746,183.54	814,018.41
23.0	327,842.07	409,802.59	491,763.10	573,723.62	655,684.14	737,644.66	819,605.17	901,565.69	983,526.21
23.5	337,759.70	422,199.63	506,639.55	591,079.48	675,519.40	759,959.33	844,399.25	928,839.18	1,013,279.10
24.5	358,043.49	447,554.36	537,065.23	626,576.10	716,086.98	805,597.85	895,108.72	984,619.59	
25.0	368,414.14	460,517.68	552,621.21	644,724.75	736,828.28	828,931.82	921,035.35	1,013,138.89	
26.0	389,624.46	487,030.57	584,436.69	681,842.80	779,248.92	876,655.03	974,061.14		
26.5	400,468.82	500,586.03	600,703.24	700,820.44	800,937.65	901,054.86	1,001,172.06		
28.0	433,987.71	542,484.64	650,981.57	759,478.50	867,975.43	976,472.36			
28.5	445,497.53	556,871.91	668,246.30	779,620.68	890,995.06	1,002,369.44			
30.0	481,073.26	601,341.57	721,609.89	841,878.20	962,146.52				
30.5	493,289.36	616,611.70	739,934.04	863,256.38	986,578.71				
31.0	505,688.70	632,110.87	758,533.05	884,955.22	1,011,377.40				
33.5	570,531.68	713,164.60	855,797.52	998,430.44					
34.0	584,089.65	730,112.07	876,134.48	1,022,156.90					
35.0	611,818.76	764,773.46	917,728.15						
36.5	654,991.78	818,739.72	982,487.67						
37.0	669,816.65	837,270.82	1,004,724.98						
40.0	763,554.26	954,442.83							
41.0	796,707.69	995,884.61							
41.5	813,658.31	1,017,072.88							
45.0	939,649.50								
46.5	997,797.29								
47.0	1,017,764.25								
50.0	1,144,015.22								

The details of advertising and selling highway bonds are frequently prescribed by law. Bids from bond houses are always made conditioned on an investigation of the validity of all proceedings leading to the issue. The attorneys for the bidders will require from the municipality certified copies of all papers concerning the transaction. There frequently is much variation in the form of the bids for a single issue. The items of denomination of the bonds, options on delivery, portion of the issue bid for, deposit of the money in stipulated banks, and items of less importance are often written into the bids.

TOTAL COST OF HIGHWAYS.

Charges included in total cost.—The first cost of construction is not the total cost of a highway. It is becoming customary to consider the cost of highways for a period of years.[1] This view of highway costs is important in the construction of highways with borrowed money. Municipal or county bonds are invariably issued for a definite term or period, and it is desirable, therefore, to know the total cost to a community during the life of the bond. Undoubtedly the best financial policy is to restrict the term of the highway bond to the probable useful life of the original type of road under actual conditions.

There is considerable difference of opinion among engineers and highway officials as to what constitutes the total cost of a highway during a given period of years. Questions arise over the interest charge on the original cost, the annual payments to amortize or retire the loan, the depreciation charge, and the repair and maintenance charge. Evidently if a repair and maintenance charge is made sufficient to maintain the road *absolutely* for an indefinite period, a depreciation charge has no place in the estimate of total annual cost. It is also apparent that total and annual costs for the loan can be made to vary at will by changing the period of the loan, i. e., the term of the bond. To make the problem more definite, it is desirable to assume, first, that the highway loan is a terminable loan and for a period not greater than the period for which the road will continue to serve with the original type of surface, grade, and alignment; and, second, that there is charged as the total cost of the road for that period all money paid by the community for that road in the form of taxes.

Although the cost of resurfacing a road or extraordinary repairs is a cost which occurs only at intervals, it is a safe and conservative plan to make an annual charge for all such work. As an example, if a water-bound macadam road is built at a cost of $8,000 per mile

[1] Cf., for example, the report of the Cambridge (Mass.) Paving Commission, June, 1911, and the 1909 Report of Public Work in Cuyahoga County, Ohio, p. 21.

with money borrowed at 5 per cent for 15 years and retired by a sinking fund, there would result the following annual expense to the taxpayers for each mile for 15 years: Interest on \$8,000 at 5 per cent, \$400; annual sinking fund to retire \$8,000 in 15 years, at $3\frac{1}{2}$ per cent interest compounded semiannually, \$413.66;[1] cost of annual maintenance, \$125; annual cost of periodic[2] resurfacing, \$400—making a total annual cost of \$1,338.66. By the annuity bond plan, the expenses would be: Annual repayments of interest and principal,[3] \$770.74; cost of annual maintenance, \$125; annual cost of periodic[2] resurfacing, \$400—making a total annual cost of \$1,295.74.

At the end of 15 years the interest and redemption charges cease, and if resurfacing is carried out as planned the surface is but two years old and the community has a property the permanent value of which represents at least 62 per cent of the original cost, or \$4,960, exclusive of the surface, and an accumulation of \$800 toward resurfacing. If the road is to continue in its original form, the annual charge for repairs and maintenance will probably increase because of increased traffic. If the annual payment of principal is reduced by extending the period of the loan, there is danger that a new loan will be necessary for more expensive construction to meet the increasing traffic before the original loan is retired. Moreover, the decrease in annual payments of interest and principal is not inversely as the increase in the period of the loan. A 30-year 5 per cent annuity bond would require an annual payment of \$520.41 per mile on the \$8,000 macadam road above cited. (See Table 36 and Pl. III, fig. 1.)

If the same method of estimating the annual cost is used for each type of road considered, the relative total cost of the various types may be computed fairly and without confusion. If a highway were built from cash in the public treasury it would theoretically still be necessary to include in the annual cost of such a highway the interest on the first cost of construction at a rate which the municipality or county could obtain by investment of its funds. The question of how long such interest should run has never been determined.[4]

In estimating the total cost of a highway for a series of years the cost of repair and maintenance is the item most frequently neglected.[5] The cost of the sinking fund or the charge for bond redemption is also sometimes forgotten. There are now outstanding bonds for highway construction where no provision has been made to retire them, although the bonds have been issued for a definite term.

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[1] Use Table 6, p. 15.

[2] At intervals of 6.5 years, at \$2,600 per mile, or 29.5 cents per square yard for a 15-foot road; no allowance of interest is made; for discussion of this point, see p. 13.

[3] See Table 36, Appendix D.

[4] Theoretically interest would run until improved road had paid for itself by saving to community.

[5] In one county of Virginia, after public highways had been constructed from the proceeds of a bond issue, the county established tollgates upon the highways in order to raise revenue for their maintenance.

Financing maintenance.—It is undoubtedly necessary, in general, to establish a direct tax for annual repair and maintenance for bond-built highways.[1] When highway bonds are issued it should be distinctly understood that there will be (besides the tax for interest and retirement) within a few years an additional tax for repair and maintenance, if the regular road tax within the county, as is most often likely, is not already sufficient to repair and maintain the new roads. This repair and maintenance charge is inevitable and, since the earning power of the road in reducing hauling costs tends to increase with the degree of maintenance, it is sound business to face the repair and maintenance charges in the beginning.

Comparisons of total costs.—When the more expensive types of highways are to be built by the proceeds of a bond issue, especially under increasing traffic, a question may fairly arise as to the relative portions of the total cost for a series of years, which should be devoted to repair and maintenance and to first construction and interest. As Table 5 shows, the cost of the hard highway surface constitutes, for standard types of construction, the largest percentage of total costs.

Up to a certain point, when the cost of the surface is increased, the cost per mile of maintenance correspondingly increases, but not usually the cost per unit of traffic. It costs more per mile to repair and maintain an ordinary macadam road, for example, than it does to repair and maintain a gravel road, and the cost per mile of repair and maintenance for bituminous-macadam roads is greater than for ordinary macadam roads. The costs of repair and maintenance of the best-built brick and concrete roads are apparently very low, and would, therefore, not follow the above rule.

The total necessary cost of a highway for a series of years can be determined only approximately and only after a study of the character and volume of traffic and a comparison of the total probable costs for the kinds of surface adapted to the traffic. It may not be economy to build a road of cheap first cost and high maintenance charges. If exact figures were available, accurate comparisons of different surfaces would be simple, but many items are still lacking. It is not known how long a concrete road will wear or what it will cost to renew it, especially if it has to be broken up and removed. The life of bituminous-macadam roads has not yet been fully determined, nor has the life of the best modern vitrified brick pavement. Absolute maintenance[2] on most pavements can seldom be continuous. Repairs or resurfacing operations will be needed at intervals which are as yet imperfectly determined.

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[1] Cf. Act of September, 1913, by Legislature of Tennessee, which establishes a maintenance tax of 2 per cent of all highway bonds.

[2] See Bulletin No. 48 of the Office of Public Roads, p. 8.

If it is assumed that a 15-foot bituminous-macadam road costs $10,500 a mile, and the corresponding 15-foot brick road $18,500 a mile, with annual (absolute) maintenance for the bituminous road at $600 per year and strict maintenance [1] for the brick road $300 per year, the necessary items for the total cost for 20 years may be stated as follows:

Bituminous-macadam:	
Cost of construction ($10,500) under 5 per cent serial bond with interest for 20 years [2]	$16,012.50
Cost of annual repair and maintenance ($600) for 20 years	12,000.00
Total cost for 20 years	28,012.50
Brick:	
Cost of construction ($18,500) under 5 per cent serial bond with interest for 20 years [2]	$28,212.50
Cost of annual repair and maintenance ($300) for 20 years	6,000.00
Total cost for 20 years	34,212.50

On the assumption made there is not as much difference in the total costs of the two road surfaces as would appear from the first costs. It is not known that $600 per mile per year will absolutely maintain a bituminous-macadam road nor that $300 per mile per year will strictly maintain a brick road, and the relative value of the two road surfaces at the end of the 20-year term is still to be determined.

The above analysis indicates a method of estimating the total cost of roads and of required bond issues. The total cost of a 15-foot concrete road, for example, may be compared with the above total costs, assuming a construction cost of about $1.35 per square yard or $11,880 a mile and an equivalent annual repair and maintenance charge between that of brick and bituminous-macadam.

EXPEDIENCY OF ISSUING HIGHWAY BONDS.

Legal restrictions on bond issues.—Nearly all States restrict the total amount of municipal bonds which may be issued to a fixed percentage of the assessed valuation. In other cases there are legal restrictions governing the amount of taxes which may be raised for highway purposes. These are examples of legal restrictions which must be clearly understood before the issue is made. The question frequently arises regarding the authority of the districts of a county to issue bonds. In a number of States the law allows the creation of highway districts or the issuance of bonds by the legal subdivisions of a county. Care must be exercised to determine to what officers the authority for such issues belongs. Instances have arisen where district road boards have undertaken the issue of bonds legally voted, but where the law provided that the county authorities and not the district authorities must issue the bonds.

[1] See Bulletin No. 48 of the Office of Public Roads, p. 8.

[2] Use Table 11, p. 18.

In nearly all States county bonds or district bonds of any kind must be authorized by a majority, or a two-thirds vote, of either the entire county or of the district.

Advantage of bond issues.—The issuance of highway bonds is essentially a method of capitalizing the resources of a community for the purpose of creating improved highways. The fundamental advantage of the bond plan is the construction of a good system of roads at once, but there are secondary advantages in building roads in long stretches and in the planning of the maintenance of such roads.

The question is not merely whether a community shall incur a debt; it is also a question as to whether the maximum economic efficiency and the full development of the public wealth will be best promoted by using public credit.

There is shown in Plate III, figure 2 the relation between the volume of traffic in ton-miles, reduction in hauling cost in cents per ton-mile, and the annual cost per $1,000 of a 20-year bond under the annuity plan. A mile of road sustaining 3,000 tons of travel per year, for example, would pay interest and retirement on $1,000 in 4 per cent bonds if the cost of hauling were reduced about 2.4 cents per ton-mile.

Emphasis has been placed in this publication on the strictly measurable economic benefits to a community from road improvement. There are many additional economic benefits and very great social benefits which are not readily measured. Increased school and church attendance is shown in repeated instances to be an immediate consequence of better roads.[1] The general stimulus to business is difficult to evaluate. It is evident, however, that business and professional men of all classes are among the first to be benefited. This is especially true of physicians. The cost of upkeep of automobiles, particularly of tires, is becoming yearly a large item and the road condition is a most serious factor for the automobilist and the users of motor trucks.

It should be understood at the outset that the question of debt itself is relatively less important than the question of sound planning and good management of the loan. The very presence of the improved road system increases the value of the county property and therefore the resources supporting the loan. It is a well-established business principle that extension of credit within safe limits is necessary for maximum results. The financing of all private enterprises by bond issues has increased very greatly. In 1908 statistics show that, during the preceding decade, bonds were issued as a method of capitalizing public and private enterprises at the rate of $583,000,000 annually.

[1] Cf. Farmers' Bulletin No. 505, "The Benefits of Improved Roads." This bulletin may be obtained from the Secretary of the U. S. Department of Agriculture.

Failure of bond issues.—Instances are not lacking where bond issues for highway purposes have proved failures. These instances are invariably due to mismanagement rather than to defective principle. Where counties have issued highway bonds the proceeds of which have been spent to construct temporary road surfaces on unimproved grades and without proper drainage, failure has necessarily resulted. There are on record in the Office of Public Roads instances where so-called macadam roads have been built with bond money by simply dumping broken stone at the wrong time of the year on muddy road surfaces without grades or alignments and without rolling or binding. (Cf. Pl. I, fig. 2.)

A typical method of mismanagement is to distribute the funds equally on all the roads in the county or district issuing the bonds. Recently in a southern State $40,000 was distributed equally over nearly 90 miles of highway in a certain district. After deducting necessary overhead expenses this sum was equivalent to about $400 per mile. Obviously no permanent results could be obtained from such a distribution. In another county, where heavy rains and severe winters could not fail to make the roads nearly impassable with the superficial construction adopted, bonds were issued to the amount of $300,000. The money was devoted to light grading on an excessive mileage without any attempt at surfacing.

Through a misunderstanding of the essential principles underlying the establishment of a proper county road system, conflicts of interest sometimes arise which cause the failure of the bond issue plan. The location of the roads to be improved should not be determined by argument, but upon sound engineering and economic principles. Before a community votes to issue bonds for highways it is necessary to understand thoroughly what roads are to be improved and the approximate cost of their construction and maintenance. Too frequently ill-advised locations are adopted.

Need for highway engineers.—Highway plans for bond issues require expert skill and professional service. Before the amount of bonds is determined, a thorough study of the needs of the county should be made and careful maps of the proposed highway system should be prepared. The sum to be issued should not be fixed until it is reasonably known what it will accomplish. It is customary for many counties to appoint a commission of business men under whose jurisdiction the bond money is expended. In other cases the county supervisor or county commissioner has the direction of expenditures. The best results have always followed where such commissions or county boards have secured the services of a highway engineer.

Guided by the costly experience of many communities, it is now becoming common for counties to adopt this plan. In all engineering construction it is customary to allow a certain percentage of the cost for engineering and supervision. There is no reason why highway building should be made an exception to this rule. At least 5 per cent of the bond issue may well be set aside for engineering and supervision alone. Money spent to hire a competent engineer [1] to make preliminary investigations before bonds are issued and to plan and supervise construction will be well spent. It is not uncommon to find counties that will repeatedly postpone the sale of bonds in order to obtain an increase of 1 per cent in a bid for $100,000 or less and then proceed to construct the roads in a most haphazard and ill-planned manner.

Benefit to nonabutting property owners.—In planning the highway system or the main market roads, as mentioned above, it will be found necessary to omit many roads the improvement of which is greatly desired by abutting landowners. The fact that such property holders must pay a tax for the bond issue is only an apparent injustice, for if the highway system is well planned the entire county will feel the benefits of the improvement. As a rule, main market roads reach the majority of producing areas, and when they are improved all land values tend to increase.

The fact that cities and larger towns are frequently taxed for bond issues to build highways outside of their own limits is sometimes made a point of debate in bond elections. It is argued that because a large part of the county wealth is within the corporate limit of such cities and towns, highway bond money should also be used to construct their streets. It is even urged that the expenditure should be made proportionate to the assessed valuation within the city limits. If the proceeds of highway bond issues were distributed in this way their purpose in many cases would be defeated. The primary object of the county highway bond issue is to build county market roads and not to improve city streets, although a high percentage of the assessed valuation may be city property.[2] It is now known that the expenditure of city taxes on country roads is a sound principle and that it is one of the best features of State aid for highways. In Massachusetts the city of Boston pays possibly 40 per cent of the total State highway fund, but not a mile of State-aid highway has been built within its limits. New York City also pays about 60 per cent of the cost of the State highway bonds. Some State laws prohibit the expenditure of proceeds of State highway bonds within corporate limits of cities or towns. The improvement of market roads results in improved marketing conditions which benefit the city. Most cities are essentially dependent upon the surrounding country for their prosperity and development. The development of suburban property for resi-

[1] In the general bond act of September, 1913, by the State of Tennessee the employment of an engineer by the county commissioner is made mandatory. In Virginia the law provides that counties building roads under a bond issue shall employ an engineer either appointed or approved by the State highway commissioner.

[2] For arguments concerning the benefits of good roads cf. Farmers' Bulletin No. 505.

dence purposes is also dependent upon highway conditions and it is becoming evident yearly that whatever makes for an increase in rural population must be encouraged. Since the introduction of motor traffic, country highways have been used to an increasing extent by city residents. In fact, the cost of maintaining many country highways has been greatly increased by the presence of city-owned motor vehicles. The general advance in facilities for doing country business from town headquarters when roads are improved is no inconsiderable factor in the commercial life of the community.

Examples of county bond-built roads.—The Office of Public Roads during the past four years has undertaken a detailed study of economic conditions in several counties which have issued bonds for highway construction. These studies have involved field work each year for from three to five years in the several counties. The detailed results of these studies are embodied in reports which are now on file in the office. Sufficient data have been gathered to emphasize and illustrate many points brought out by the discussion in the present bulletin.

The locations of the studies were Dinwiddie, Lee, Spotsylvania, and Wise Counties, Va.; Dallas County, Ala.; Lauderdale County, Miss.; Manatee County, Fla.; and Franklin County, N. Y. Although no special field studies were made in Wayne County, Mich., statistics for that county have also been compiled.

TABLE 18.—*Financial items.*

County and State.	Highway bonds.	Term in years.	Nominal interest.	Valuation year of issue.	Per cent of valuation in highway bonds.
Dinwiddie, Va	$105,000	20 and 30	5 and 6	$3,661,897	2.84
Lee, Va	440,000	Serial.	5 and 5½	3,014,405	14.59
Spotsylvania, Va	183,000	30	5	[1] 1,962,956	9.32
Wise, Va	960,000	30	5	11,011,780	8.71
Manatee, Fla	250,000	30	5	2,450,000	10.20
Dallas, Ala	410,000	30	5	13,330,355	3.08
Lauderdale, Miss	350,000	30	5 and 5½	16,443,301	2.13
Franklin, N. Y	500,000	60	4½ and 5	12,293,434	4.07
Wayne, Mich	2,000,000	Serial.	4	467,400,635	.43

[1] 1913.

The total amount of bonds issued by these counties during the years 1900 to 1913, inclusive, was $5,188,000, and with the exception of Lee and Wayne Counties, where the bonds were issued under the serial plan, and Franklin County, N. Y., where they are to run for 60 years, they are straight terminable bonds for 30 years. Table 18 summarizes the financial items for each county.

In some instances no preparation has been made for establishing a sinking fund to retire bonds at maturity. In several of these counties there is no provision whatever for systematic maintenance. In Virginia the State law provides that State aid allotted to counties may be used for the redemption of bond issues where the roads are built in accordance with the requirements of the State highway commissioner and under the supervision of his engineers. In four counties in Virginia the roads are built under this plan. In Dallas County, Ala., the construction of bond-built roads was in charge of the four district commissioners and the probate judge. In Manatee County, Fla., the roads were built under the supervision of the five district county commissioners. In Lauderdale County, Miss., the county supervisors appointed a road commission of three members to construct the roads under the bond issue, and a highway engineer was employed and all work done by contract. In Franklin County, N. Y., the roads were constructed by the county road commissioners and the county superintendent of roads. In Wayne County, Mich., the roads were built by the board of county road commissioners, appointed by the county board of supervisors.

The following table shows the mileage and cost of roads constructed in each county:

TABLE 19.—*Mileage and cost of roads in nine counties where bonds were issued.*

County and State.	Miles built.	Per cent of total mileage in county.	Kind.	Average cost per mile.
Dallas, Ala	197	19.0	Gravel	$3,700
			Sand-clay	1,650
Manatee, Fla	64	12.8	Macadam	4,250
			Shell	2,400
Lauderdale, Miss	84	10.5	Macadam [1]	6,500
			Sand-clay	1,900
Spotsylvania, Va	41	10.0	Gravel and sand-clay	2,200
Dinwiddie, Va	125	25.0	Gravel and top soil	1,689
Franklin, N. Y	124	9.0	Gravel	2,200
			Macadam	3,250
Lee, Va	84	18.2	do	7,400
			Earth graded	5,000
Wise, Va	131	43.7	Macadam	8,000
			Earth graded	5,300
Wayne, Mich	83.5	5.8	Concrete [2]	13,200

[1] Surface treated with petroleum asphalt.

[2] Eighty miles.

In no one of these counties, with the exception of Detroit, in Wayne County, Mich., were there any large cities. The roads were, for the most part, constructed as market roads radiating from the main market towns in the county, as may be seen from the maps of Plates IV, VI, and IX. The economic benefits accruing to the several counties from the improvement of the roads are already apparent, and in several instances have been extraordinary. (Cf. Pls. V, VII, and VIII.)

In Dallas County, Ala., and Lauderdale County, Miss., cotton is the principal crop, although in the latter county lumber is also an important commodity. Lumber and ties form, also, the principal commodity hauled in Spotsylvania County, Va. In Dinwiddie County the principal commodities are tobacco, peanuts, and hay; in Lee County farm and dairy products, hardwood, lumber, and coal; and in Franklin County, N. Y., milk and miscellaneous farm products.

In Manatee County, Fla., the principal crops are citrous fruits and early vegetables, which are shipped north. In Wayne County, Mich., the city of Detroit is the center of the road system and attracts a very large volume of miscellaneous traffic. The estimated annual tonnage hauled over the bond-built highways in almost every instance is sufficiently large to produce, by an assumed reduction of a few cents per ton-mile in cost, a sufficient operating income to cancel the annual interest and retirement fund required by the bonds. The relation of these items is summarized in the following table:

TABLE 20.—*Summary of relation between bond requirements and reduced cost of hauling.*

County and State.	Total annual ton-miles estimated at minimum.	Approximate cost of annual interest and redemption on highway bonds.	Equivalent necessary reduction (cents per ton-mile).
Dallas, Ala	600,000	$28,333	4.7
Manatee, Fla	[1] 200,000	17,342	8.7
Lauderdale, Miss	720,000	24,530	3.4
Spotsylvania, Va	574,720	12,695	2.2
Dinwiddie, Va	212,500	8,633	4.1
Franklin, N. Y	201,544	25,544	12.6
Wayne, Mich	4,353,966	[2] 179,882	4.1

[1] Rough estimate. [2] Equivalent for annuity bond.

The increases in the value of land adjacent to the improved roads are especially noteworthy. In Manatee County, Fla., land increased in value $20 per acre from 1911 to 1912, and a mile away from the road the increase was $10 per acre. In Spotsylvania County, Va., land which formerly sold at an average of $24.74 per acre changed hands within three years at an average of $44.74. In Dinwiddie County, land between 5 and 10 miles from Petersburg advanced on an average from $15.25 to $30 in about 15 instances, and land 10 miles from town increased, on an average in 16 instances, $16.32 an acre. On eight pieces of land in Franklin County, selected at random, there was an increase in value of 27.8 per cent after the improved roads were built, and in Lee County, Va., land advanced 25 per cent.

The construction of the bond-built highways in several of the counties herein mentioned has been of decided benefit to school attendance. In Spotsylvania County one consolidated school replaces three one-room schools, and another consolidated school is planned. In Dinwiddie County school attendance increased 17½ per cent in one year on the improved roads, and several school wagons carrying 24 pupils each have been put in service. In Lee County school attendance along the improved roads shows an average of 71 per cent against 62 per cent along other roads. In Wise County several successful school consolidations have been effected since 1909. The Pole Bridge School in this county on the road from Coburn to Wise replaces four one-room schools.

APPENDIX A.

STATE HIGHWAY BONDS.

TABLE 21.—*Complete list of State highway bonds.*

State.	Year.	Amount (by years).		Rate (per cent).	Term (years).	How redeemed.
		Voted.	Issued.			
California	1910	[1]$18,000,000		4	50	$400,000 annually after July 1, 1917.
	1912		$2,000,000	4	50	
	1913		3,390,000	4	50	
Total		18,000,000	5,390,000			
Connecticut	1907	[2]4,500,000	1,500,000	3½	22	$205,000 annually.
	1909		1,500,000			
	1911	[3]3,000,000	2,000,000	4	25	$120,000 annually.
	1913	[3]3,000,000	2,000,000	4	25	Do.
Total		10,500,000	[4]7,000,000			
Idaho[5]	1905	50,000	50,000	4	30	Sinking fund.
	1907	18,000	18,000	4	20	Do.
	1909	22,000	22,000	4	10 and 20	Do.
	1911	136,000	136,000	4, 4½, 5	5, 6, 10, 20	Do.
	1912	29,000	29,000	4½ and 5	20	Do.
	1913	250,000	250,000	4	20	Do.
Total		505,000	505,000			
Maine[6]	1912	2,000,000				
	1913		300,000	4	40	$7,500 annually.
Total		2,000,000	300,000			
Maryland[7]	1908	5,000,000	500,000	3½	15	Sinking fund.
	1909		1,000,000	3½	15	Do.
	1910	[8]1,000,000	1,000,000	3½ and 4	15	Do.
	1911		1,250,000	3½ and 4	15	Do.
	1912	[9]3,170,000	2,250,000	([9])		Do.
	1913		2,646,000			
Total		9,170,000	8,646,000			
Massachusetts	1894	300,000	300,000	3½	26	Do.
	1895	400,000	400,000	3½	25	Do.
	1896	600,000	600,000	3½	24	Do.
	1897	800,000	700,000	3½	30	Do.
	1898	400,000	300,000	3	30	Do.
	1899	500,000	400,000	3	30	Do.
	1900	500,000	400,000	3	30	Do.
	1901	500,000	350,000	3	30	Do.
	1902	500,000	375,000	3 and 3½	30	Do.
	1903	2,250,000	400,000	3½	30	Do.
	1904		300,000	3½	28	Do.
	1905		250,000	3½	25	$10,000 annually.
	1906		300,000	3½	30	Do.

[1] *California.*—Proceeds of bond issue to be expended on a continuous and connected State highway system running north and south through the State, traversing the Sacramento and San Joaquin Valleys and along the Pacific coast, by the most direct and practicable routes, connecting the county seats of the several counties through which it passes, together with such branch roads as may be necessary to connect therewith the several county seats lying east and west of such State highway. No limitation on annual expenditure.

[2] *Connecticut.*—To be expended during the six fiscal years ending Sept. 30, 1913. Bonds to be paid in 22 annual installments by appropriation from general fund.

[3] $1,000,000 for improvement of public roads; $2,000,000 for improvement of trunk-line roads. The 1911 and 1913 bond issues mature in 1936, but may be redeemed by the State treasurer whenever and in such manner as he deems to be for the best interest of the State. They are not specifically known as road bonds; but the 1911 highway appropriation was specifically designated by the legislature to be from the proceeds of the $6,000,000 State issue of bonds. The 1913 appropriation is made from the treasury, while the treasurer is, in a special act, authorized and instructed to issue $4,000,000 additional bonds to meet the needs of the State.

[4] For trunk-line roads only.

[5] *Idaho.*—For various roads and bridges specified in the act authorizing each bond issue, except $200,000 in 1913, which is expended under State highway commission.

[6] *Maine.*—Not to exceed $2,000,000 shall be outstanding at any one time. To be expended in the construction of State highways, the whole cost to be paid by State, except where a town may desire the joint State-aid fund to be applied on State highway.

[7] *Maryland.*—For State roads.

[8] Not to exceed $250,000 to be issued in any one year, beginning Jan. 1, 1911.

[9] To be issued in amounts of not less than $500,000 at a time upon request of the State roads commission. Rate of interest to be fixed by the governor, the comptroller of the treasury, and the State treasurer.

TABLE 21.—*Complete list of State highway bonds*—Continued.

State.	Year.	Amount (by years).		Rate (per cent).	Term (years).	How redeemed.
		Voted.	Issued.			
Massachusetts	1907	$2,500,000	$360,000	3½	30	$12,000 annually.
	1908		495,000	3½	30	$16,500 annually.
	1909		380,000	3 and 3½	10–30	$220,000 deferred serial, 1920–1939.
	1910		285,000	3½	10–30	$180,000 deferred serial, 1920–1939.
	1911		310,000	3½	10–30	$200,000 deferred serial, 1921–1940.
	1912	5,000,000	435,000	3½	10–30	All but $175,000 deferred serial.
	1913	[1] 115,000	1,110,000	3½		Serial.
Total		14,365,000	8,450,000			
New Hampshire	1909	[2] 1,000,000				
	1910		250,000	3 and 3½		Deferred serial, 1914–1917.
	1911		250,000	3½		Deferred serial, 1917–1921.
	1912		250,000	3½		Deferred serial, 1921–1924.
	1913	[3] 300,000	[4] 250,000	3½		
Total		1,300,000	1,000,000			
New Mexico [5]	1912	500,000		4		
Total		500,000	(6)			
New York	1906	[7] 50,000,000				Sinking fund.
	1907		1,000,000	3	50	Do.
	1908		5,000,000	4	50	Do.
	1909		5,000,000	4	50	Do.
	1910		5,000,000	4	50	Do.
	1911		10,000,000	4	50	Do.
	1912	[8] 50,000,000	8,000,000	4	50	Do.
	1913		16,000,000	4½	50	Dated Sept. 1, 1913; sold Jan. 14, 1914.
			5,000,000	4½	50	
Total		100,000,000	55,000,000			
Rhode Island	1906	[9] 600,000		3	30	Sinking fund.
	1909	600,000		3½	30	Do.
	1912	[10] 600,000		4	30	Do.
Total		1,800,000	1,800,000			
Utah	1911	[11] 260,000		4	23	Deferred serial, 1922–1934.
Total		260,000	260,000			
Washington [12]	1911	190,000	125,000	4	12	Paid from State highway fund.
Total		190,000	125,000			
Totals		158,590,000	88,476,000			

[1] *Massachusetts.*—Authorized for special State roads by legislature, 1913.

[2] *New Hampshire.*—Not to exceed $250,000 to be issued in any one year, and the proceeds to be used exclusively for State aid in the construction of the three trunk lines to be designated by the governor and council from the Massachusetts State line in a northerly direction.

[3] To be used for State aid in constructing trunk-line highway to be designated by the governor and council.

[4] Not sold Dec. 1, 1913.

[5] *New Mexico.*—These bonds shall be in denominations of $1,000, numbered 1 to 500, the first 20 of which shall be payable on Jan. 1, 1919, and 20 of said bonds, in consecutive numerical order, shall be due and payable on July 1 annually thereafter until and including July 1, 1942. The proceeds are to be expended for the construction and maintenance of a system of State highways.

[6] Bonds not sold Dec. 31, 1913.

[7] *New York.*—These bonds were to be issued in two classes, to be known as A and B. Class A is coupon or registered, and redeemable from a State sinking fund, while Class B bonds were to be registered and redeemable from a redemption fund provided by the counties and towns wherein the proceeds thereof should be applied to the improvement of highways.

[8] The act of the legislature authorizing this issue of bonds was ratified and rendered operative by vote of the people at the general election, November, 1912. Of the proceeds, $20,000,000 shall be devoted to State highways, to be built at sole cost of the State, and $30,000,000 to county highways, to be built at joint expense of State and county.

[9] *Rhode Island.*—$200.000 to be issued before Jan. 1, 1907, and the balance on or before Jan. 1, 1908; the proceeds to be used in building a system of State roads under the direction of the State board of public roads.

[10] To be used for construction, reconstruction, and maintenance.

[11] *Utah.*—The proceeds to be divided equally among the counties of the State, exclusive of Salt Lake County, to be used in the construction and maintenance of State roads and bridges therein. Bonds dated July 1, 1911.

[12] *Washington.*—For purchase of bridge across the Columbia River at Wenatchee.

STATE BOND ISSUES DEFEATED.

Colorado.—The proposition to issue $10,000,000 in State bonds for roads was submitted to the people of Colorado at the general election in November, 1912, and was defeated. The proposition can not be again submitted to the people within a few years.

Ohio.—At the general election in November, 1912, there was submitted to a vote of the people of Ohio a proposition to issue $50,000,000 in State bonds to construct a system of intercounty highways. The vote on this proposition numbered about three-quarters of a million, and the bond issue was defeated by 2,017. One remarkable fact in connection with this vote was that the cities of the State gave substantial majorities for the bond issue, while the rural vote was substantially against it, and to such an extent as to overcome the city majority, although about 80 per cent of the taxes which would have been levied to take care of the interest and sinking fund of the bonds would have been paid by the cities.

Rhode Island.—On June 3, 1913, a special election was held in the State of Rhode Island on the issuance of $700,000 of State bonds for the purpose of completing a system of State roads. At this election only about 14 per cent of the voters of the State attended the polls, and the proposition was overwhelmingly defeated.

Pennsylvania.—On November 3, 1913, at a general election a proposed issue of $50,000,000 in highway bonds was defeated, although the proposition carried in Philadelphia and Pittsburgh.

APPENDIX B.

APPROXIMATE LISTS OF COUNTY AND DISTRICT HIGHWAY AND BRIDGE BONDS; TOWNSHIP HIGHWAY AND BRIDGE BONDS; COUNTY, DISTRICT, AND TOWNSHIP HIGHWAY AND BRIDGE BONDS VOTED IN 1912 AND 1913; COUNTIES, DISTRICTS, BEATS, AND TOWNSHIPS GIVING COMPLETE MILEAGE RETURNS OF ROADS BUILT UNDER BOND ISSUES; TOWNSHIPS AND TOWNS GIVING COMPLETE MILEAGE RETURNS OF ROADS BUILT UNDER BOND ISSUES; SUMMARY OF ALL HIGHWAY AND BRIDGE BONDS VOTED TO JANUARY 1, 1914.

TABLE 22.—*County and district highway and bridge bonds.*[1]

ALABAMA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total Amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Autauga	$65,000	30	5	Limestone	$135,000	30	4½
Blount	150,000	30	5	Madison	172,500		5
Bullock	160,000	30	5	Marion	100,000	20	5
Butler	155,000			Marshall	130,000	30	5
Colbert	200,000	30–35	5	Mobile	500,000	20	5
Conecuh	200,000			Montgomery	850,000		4½–5
Crenshaw	125,000			Morgan	240,000	30	5
Dallas[2]	410,000	30	5	Perry	126,000	30	5
Elmore	170,000	30	5	Pike	192,000		4½
Escambia[3]	38,000		5½	Russell	100,000	30	5
Hale	100,000			St. Clair	85,000	30	5
Jackson	250,000			Sumter	120,000	20	5
Jefferson	200,000	30	6–5–6				
Lawrence	123,000	30	6	Total	5,121,500		
Lee	25,000	30	4½				

ARIZONA.

Apache	$30,000		5	Maricopa—Con.			
Greenlee: Duncan[4]	16,000		6	Special road district 2	$40,000	20	6
Maricopa:				Mohave	100,000		5
Phoenix (city)[5]	60,000	20	5	Yuma	500,000		
Mesa (city)[5]	2,000	20	5				
Special road district 1	30,000	([6])	6	Total	808,000		
Special road district 1	30,000	20	6				

ARKANSAS.

Benton	$2,815	12		Montgomery	$10,000		
Crawford[3]	174,000			Sebastian: Ft. Smith[3]	600,000		
Jefferson	45,500	13	6	Woodruff: District 1	30,000	20	6
Lee	151,000						
Lonoke	205,000	20	5	Total	1,218,315		

[1] In 21 States highway and bridge bonds have also been issued by townships. See list following.
[2] Includes $60,000 of bridge bonds.
[3] Bridge bonds only.
[4] Bridge.
[5] To cover partial cost of improvement of Phoenix to Roosevelt Dam road.
[6] Serial.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

CALIFORNIA.

Counties.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Alpine [1]	$4,800		5	Riverside	$1,500,000		
Contra Costa	300,000			Sacramento [3]	825,000	[2] 40	4½
Fresno [1]	80,000		6	San Diego	1,250,000	40	4½
Glenn	450,000	(2)	5	San Joaquin	1,850,000	40	5
Humboldt	15,000	20	7–9	San Mateo	1,298,000	7–10–40	5
Kern	2,500,000	25	5	Santa Barbara	290,000	20	6
Lake	20,000		5	Tehama	3,000		6
Los Angeles	3,500,000	40	4½	Ventura [1]	275,000		5
Orange	1,370,000		5				
Plumas	100,000	10–25	4	Total	15,630,800		

COLORADO.

Counties.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Delta	$71,700		5
Garfield	28,000		6
San Miguel	35,000		6
Total	134,700		

DELAWARE.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Kent	$30,000	20	5	Districts 1–10	$50,000	5–11	4
New Castle	[4] 1,285,000	20–51	4–4½–5				
Sussex [1]	30,000	5–24	4½	Total	1,395,000		

FLORIDA.

Alachua	$40,000			Nassau	$180,000		
Bradford: Hampton	25,000	20	6	Orange	800,000	30	5
Clay	150,000			Palm Beach	345,000	30	4½
Columbia	40,000		6	Pasco	150,000	30	5
Dade	250,000	20	5	Pinellas	370,000	30	5
De Soto	250,000			Polk: Winterhaven	130,000		
Duval	1,050,000	25	5	Putnam	155,000		5
Franklin	20,000	20	4½	St. John	70,000		
Hernando	300,000	30	5	St. Lucie	200,000		
Hillsborough	1,400,000	30	5	Seminole	200,000		
Holmes: 1 district	40,000	30	6	Walton	70,000	20	6
Jackson	300,000	30	4				
Lake	500,000	[2] 15–30	5	Total	7,285,000		
Manatee	250,000	30	5				

GEORGIA.

Ben Hill	$75,000		5	Miller	$48,000		
Bleckley	8,000			Spalding	10,000		
Clarke	100,000		4	Towns	4,000		
Colquitt	400,000			Troup	200,000		
Gordon	8,000			Turner	20,000		5
Hancock	51,000	30	5				
Laurens	202,000		5	Total	1,176,000		
Marion	50,000						

[1] Bridge bonds only.
[2] Serial.
[3] Bridge bonds, $225,000.
[4] Of this amount $275,000 was for bridges.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

IDAHO.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Ada	$234,484	10–20	4½–5	Kootenai	$83,071	....	....
Bear Lake	45,000	4	5½	Lincoln	130,000	10–20	6
Boise	70,000	20	....	Oneida: Districts 1–3	59,000	....	5
Canyon	[1] 198,782	10–20	4–5	Twin Falls	[3] 100,000	10–20	5½
Custer [2]	15,000	....	6	Washington [2]	6,500	....	6
Fremont: District 1	120,000	10–20	6				
Gooding	160,000	....	....	Total	1,221,837	....	....

ILLINOIS.

Edwards: District 3	$3,000	2	6	Wabash	$12,000	[5] 5	5
Jackson [4]	36,320	1–20	4½				
Peoria [4]	320,000	....	....	Total	420,320	....	....
St. Clair: Centerville District	49,000	[5] 20	5				

INDIANA.

Adams	$151,550	10	4½	Marshall	$86,400	15	4½
Allen	53,840	10	4½	Martin	189,881	....	4½
Bartholomew	365,572	10	4½–5	Miami	636,656	10–20	4½
Boone	223,260	10	4½	Monroe	315,000	....	....
Carroll [6]	80,000	....	4–6	Montgomery	1,795,723	....	....
Cass	569,258	....	....	Morgan	341,200	10	4½
Districts 1–3	112,425	10	4½	Newton	67,021	....	....
Clark	51,250	....	....	Ohio	74,000	10	5
Clay	73,800	10	4½	Owen	199,693	20	4½
Crawford	46,000	....	4½	Parke	390,996	....	....
Daviess	90,000	10	4½	Porter: Districts 1–3	1,055,880	10–20	4½–5
Dearborn	232,272	1–20	4½	Posey: Districts 1–3	648,244	....	4½–6
Decatur	[7] 63,880	10–15	4½	Putnam	54,300	....	....
Delaware	100,000	10–20	4½	Districts 1–3	58,689	10	4½
Dubois	196,949	....	....	Randolph	27,150	....	5
Fayette	53,610	10	4½	Ripley	800,000	....	4½
Fountain	137,950	10	4½	Rush	489,000	10–20	4½–5
Franklin	111,000	....	3½–5	St. Joseph [6]	523,200	10	4½
Fulton [6]	50,000	20	4½	Shelby [6]	144,455	20	4½–6
Gibson	77,300	10	4½	Spencer	105,000	....	3½
Greene	42,499	10	4½	Starke	41,000	10	4½
Hancock	[8] 273,500	1–10	4½–5	Sullivan	80,982	10	4½
Harrison	43,220	20	4½	Switzerland	55,652	....	....
Henry	44,269	....	....	Tippecanoe [6]	260,000	10	4½
Huntington	341,932	10	4½	Tipton: Districts 1–3	673,140	10	4½
Jackson	[9] 29,640	10	4½	Union	60,000	....	....
Jasper	127,500	....	....	Vanderburg	266,196	10	4½
Jay	50,370	10	4½	Vermilion	462,800	....	4–4½
Jefferson	113,525	20	4½	Vigo	305,000	....	4½
Jennings	69,300	10	4½–5	Wabash	145,320	10	4½
Knox	189,360	10	4½	Wayne	88,200	10	4½
Kosciusko	1,440	....	....	Wells	[11] 477,791	....	....
Laporte	949,640	20	4½	White	513,000	10	4½
Lawrence	93,000	....	....	Whitley	8,369	....	....
Madison	45,000	10	4½				
Marion	[10] 1,378,000	10–20	3½–4½–5	Total	18,072,049	....	....

[1] Bridge bonds $151,162.
[2] Bridge bonds.
[3] $50,000 for bridges.
[4] Bridge.
[5] Serial.
[6] Bridge bonds only.
[7] Bridge bonds $30,000.
[8] Bridge bonds $25,000.
[9] Bridge bonds $15,000.
[10] Bridge bonds $200,000.
[11] Outstanding.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

IOWA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Adams	[2] $102,298			Iowa [1]	$50,000		
Allamakee [1]	24,000			Jackson [1]	137,000	20	4–5
Audubon [1]	42,000			Kossuth [1]	[7] 137,738	6–14	4½
Blackhawk	[3] 11,226			Lee [1]	50,000		
Boone	60,450	12	4½	Lucas	31,600		4½
Buchanan	[3] 15,087			Madison [1]	45,000	3–17	4½–5
Buena Vista	[3] 16,797			Mahaska	117,000		4½
Calhoun [1]	40,000			Marion [1]	107,000	10–20	4–4½
Carroll	40,000		4	Mills	27,000		
Cass [1]	[4] 162,066		4–4½	Palo Alto	4,000		
Cedar [1]	23,000			Plymouth	20,000		5
Cherokee	25,000			Polk	1,219,900		3½–5
Clarke	19,000			Pottawattamie	[3] 37,290		
Clinton [1]	57,000		4½	Sac [1]	25,000		
Crawford	50,000			Shelby [1]	23,092		
Dallas	67,000			Union	96,000		4–4½–5
Davis [1]	47,500		4½	Van Buren	109,000		4½
Decatur	19,000		4½	Wapello [1]	91,000		
Delaware	[3] 3,126			Warren [1]	163,000	20	4
Des Moines	70,000			Winneshiek	[8] 160,000		
Dickinson [1]	10,000			Woodbury [1]	[9] 63,748		
Dubuque	[3] 37,599			Wright	[10] 149,452	9–15	4½–5
Fayette [1]	[5] 55,352		4½				
Floyd	[3] 4,187			Total	[11] 4,006,314		
Fremont [1]	[6] 137,806	20	4½–5				

KANSAS.

Bourbon	$2,700			Marion	$6,000	5–9–11	6
Cloud	13,675			Pawnee [1]	8,000		4½–5
Douglas	66,500		4½	Reno	12,800		6
Edwards [1]	20,000			Sedgwick	101,550	10	5
Geary	86,150		4	Wyandotte	[12] 695,000	20–30	4½
Gray	5,000		6				
Hamilton [1]	31,000	25	4	Total	1,132,375		
Johnson	84,000		5				

KENTUCKY.

Bath	$38,000			Madison	$70,000		
Boyle	4,000		4	Mason	60,000		
Bullitt	50,000		5	Montgomery	29,000		
Carroll	40,672		4–5–6	Nicholas: Districts			
Christian	202,000			1–4	40,000	25	4
Clark	60,000			Ohio	30,000		4
Franklin	23,000			Owen	170,000		5
Gallatin	38,500		4–6	Pendleton	175,000		4½–5–6
Garrard	33,000		4	Robertson	10,400	5–8	5
Grant	90,000		4½–6	Scott	196,000		4–5
Harrison	37,500			Trimble	120,000		
Kenton	197,100			Woodford	17,500		
Lewis	6,200						
Lincoln	22,000			Total	1,759,872		

[1] Bridge bonds only.
[2] Includes $16,298 outstanding warrants.
[3] Outstanding bridge warrants.
[4] Includes $4,060 outstanding bridge warrants.
[5] Includes $5,352 outstanding bridge warrants.
[6] Includes $8,806 outstanding bridge warrants.
[7] Includes $60,738 outstanding bridge warrants.
[8] Includes $65,000 outstanding bridge warrants.
[9] Includes $20,748 outstanding bridge warrants.
[10] Includes $54,452 outstanding bridge warrants.
[11] County officials may issue bonds to pay accumulated outstanding warrants and the above list for the most part represents such funded warrants, all for bridges. It is customary to pay, in most instances, interest at 4, 4½, and 5 per cent.
[12] Bridge bonds $100,000.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

LOUISIANA.

Parishes[1] and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Parishes and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Assumption	$86,000	10	5	Jefferson	$200,000		
Bossier	175,000	1–40	5	Lafayette	75,000	25	5
Calcasieu	900,000	25	5	Plaquemines	60,000		
De Soto	60,000	10	5	Tangipahoa: District 2	75,000	30	5
East Baton Rouge	22,000	10	5	Tensas	47,000		
District 1	15,000	20	5	Washington	116,597	2–4	5
Franklin	16,914		5	Total	1,932,840		
Iberia	70,000	10	5				
Iberville: Districts 1, 5, and 6	14,329	1–10	5				

MARYLAND.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Allegany	$10,000	2½	5	Kent [2]	$10,000		5
Anne Arundel	37,000		5	Montgomery	144,500	25	4½
Calvert [2]	3,000		5	Prince Georges	16,000	30	5
Caroline	50,000	20	5	Queen Annes	63,000		
Cecil	100,000		5	Talbot [2]	37,000		
Charles	10,000		5	Worcester	100,000	25	5
Dorchester	43,000		4				
Frederick	127,000	15–30	4½	Total	750,500		

MASSACHUSETTS.

Barnstable [2]	$14,000			Norfolk [2]	$50,000	(3)	4.92
Berkshire	5,000	1–2	4¼	Plymouth [2]	20,000		4
Bristol	7,000	1–3	4½				
Essex	661,000		3½–4	Total	813,000		
Nantucket	56,000	5	4				

MICHIGAN.

Alger	$150,000			Mackinac	$100,000	10–26	5
Alpena	100,000	20	5	Manistee [2]	32,000		
Baraga	40,000		6	Mason	100,000		
Bay	255,000			Menominee	50,000		
Berrien	500,000	15	4	Midland	56,000	15	5
Delta	162,500			Muskegon [2]	25,000	15	4½
Emmet	225,000			Ontonagon	38,000	10	5
Genesee	700,000	10–20	4½	Ottawa	600,000		
Gogebic	150,000	10	4½	Schoolcraft	40,000		5
Houghton	30,000		6	Wayne	2,000,000	15	4
Ingham	63,652			Wexford	50,000		
Ionia	20,000						
Iron	160,000		5	Total	6,382,152		
Kent	735,000	20	4½				

MINNESOTA.

Aitkin [2]	$16,000		6	Lake	$20,000	4	6
Anoka [2]	40,000		4	Mahnomen	5,000	20	4
Beltrami	631,350	20	4	Ramsey [2]	75,000	30	4½
Cook	60,000			St. Louis	300,000		
Crow Wing [2]	50,000		6	Winona	50,000	5–7	5
Hennepin	110,000	30	4½				
Itasca [2]	31,000	20	5	Total	1,388,350		

[1] Parishes are equivalent to counties. [2] Bridge bonds only. [3] Nine months.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

MISSISSIPPI.

Counties, beats,[1] and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Adams	$150,000		
Alcorn	95,000		5
Attala	50,000	25	5
Benton	6,000		
Bolivar	392,000		4½–6
Calhoun: Beat 1	125,000	25	6
Chickasaw: Beat 3	220,000	20	5
Claiborne	75,000	20	5
Clay: Beats 1–3	221,000	10–25	5–6
Coahoma	225,000		4½
Copiah	305,000		
Beat 2	75,000	25	6
Covington	50,000	30	5
De Soto: Beats 1, 2, 3, and 5	250,000		6
Forrest	120,000		5
Beats 1 and 3	100,000	40	5
Franklin[2]	35,000		5
George	30,000		
Greene	52,000	1–10	5–6
Grenada	[3] 75,000	20	4½
Hancock	[4] 200,000	5–20	1½–2½–6
Hinds	300,000	25	5
Beats 1 and 5	200,000	25	5
Issaquena	[5] 59,500	40	6
Itawamba	65,000		
Jackson	160,000		5
Jasper	25,000		
Jefferson	40,000		
Jefferson Davis	20,000	20	5
Jones	20,000		
Beat 2	50,000	25	5
Lafayette	180,000	25	5½–6
Lamar	71,000		5
Lauderdale: Beats 1 and 5	350,000	30	5–5½
Lawrence	25,000		
Lee	250,000		
Beats 1 and 2	80,000	25	5½–6
Leflore	$300,000	20	5
Lincoln	200,000	25	5
Lowndes: Beat 2	50,000	10–20	5
Marshall	20,000		5
Monroe	535,000		6
Montgomery	40,000		
Neshoba	100,000		
Noxubee	380,000		
Beats 2, 3, and 5	377,500		
Oktibbeha	20,000		
Panola	50,000		6
Perry	80,000		5
Pike	200,000		
Pontotoc	25,000	20	
Prentiss	50,000		
Beat 1	40,000	25	6
Quitman	174,000		4–4½
Rankin	30,000		5
Brandon	10,000		
Scott	75,000		
Sharkey	50,000		5
Simpson	40,000	20	5
Beats 1 and 2	40,000	20	5½
Smith	40,000		
Tallahatchie	140,000		5–6
Beats 1 and 5	75,000	25	6
Tishomingo	35,000		6
Tunica	50,000		4
Union	50,000		6
Warren	[6] 369,000	20	5
Washington	100,000	25	5
Wilkinson[2]	31,372	10–20	5
Yalobusha	62,000	25	5
Beats 2 and 4	48,000	25	5½–6
Yazoo: Four beats	77,500	25	6
Total	8,710,872		

MISSOURI.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Boone[2]	$120,000	2–25	5
Callaway	100,000		
Cedar	19,000		
Christian	6,000		6
Clinton	4,000		5
Clay: Two districts	135,000		
Cooper	3,000		6
Dade	77,000		4
Franklin	325,000	10–20	6
Greene	238,000		6
Grundy	5,000		6
Howell	30,000		
Jefferson	30,000		
Laclede	72,000		4
Lafayette	$125,000	1–15	5½
Lawrence: Mt. Vernon	50,000		
Mississippi	7,000	19	6
New Madrid:			
King's Highway	93,000		
Malden Risco	20,000		
Newton: Neosho	30,000	15	6
Nodaway	15,000		
Pettis	200,000		5
Stone	10,000	17	6
Taney	7,500		
Total	1,721,500		

1 Counties are subdivided into beats.
2 Bridge bonds only.
3 Twelve miles of levee.
4 Of this amount $150,000 includes bridges, sewers, and culverts.
5 Bridge bonds, $20,000.
6 Of this amount $110,400 was issued for building bridges.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

MONTANA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Blaine	$40,000	20	5	Ravalli	$72,106		
Broadwater	102,000			Rosebud	[3] 328,000		4½–6
Carbon	90,000	20	5	Sanders	130,000		5
Cascade	60,000	20	5	20 districts	15,000	5–20	5
29 districts [1]	45,000	20	5	Sweet Grass	35,000		4½
Custer	320,000	20	4½	Teton	100,000		
Dawson	100,000		4½	33 districts	[4] 100,000	20	5
Flathead	177,500		5	Valley [1]	65,000		
Lewis and Clark	105,000	20	4½	Yellowstone [1]	70,000		
Lincoln	125,000	20	5				
Meagher	30,000			Total	2,239,606		
Musselshell	[2] 130,000	20	5				

NEBRASKA.

Blaine	$5,000		6	Lincoln	$15,000		
Dawson [1]	6,000			Morrill [1]	17,000		4½–5
Douglas	[5] 308,000		4½	Nance [1]	82,500		3–7
Garfield [1]	4,000		5	Scotts Bluff	37,000		5–6
Keith [1]	49,000		4–6				
Keyapaha [1]	30,000		3½–5	Total	553,500		

NEVADA.

Churchill	$23,000	2–11		Washoe [1]	$97,000		5–6–8
Douglas	15,000		4¾–5				
Ormsby	40,000	20	5	Total	175,000		

NEW JERSEY.

Atlantic	$307,000		4–5	Middlesex	$781,500		3½–4½
Bergen	2,121,000		4–4½	Morris	400,000		4
Burlington	55,000	15	4½	Ocean	35,000	30	5
Camden	348,900		4–4½	Passaic	[6] 941,500	14–17	4–4½–5
Cape May	329,300	30	4½	Salem	45,000		4
Cumberland	43,000		4½	Somerset [1]	75,000		
Essex	1,140,505		4	Sussex	154,100		4
Gloucester	200,000		4–4½	Union	615,000		4–4½
Hudson	6,098,977	50	4–4½	Warren [1]	30,000	5–10	4
Hunterdon	232,000	30	4				
Mercer	434,000	30	4–4½	Total	14,386,782		

NEW MEXICO.

Bernalillo [7]	$100,000	10–30	4½	San Juan [1]	$18,000	20–30	6
Dona Ana	100,000	32	5				
Eddy [1]	28,500	10–20–30	6	Total	246,500		

[1] Bridge bonds only.
[2] Of this amount $29,970 was used for building three bridges; balance for 300 miles of road.
[3] Of this amount $113,000 was for bridges.
[4] Of this amount $30,000 was for bridges.
[5] Including inheritance tax.
[6] Of the $136,000 voted in 1913, $26,000 was used for a bridge.
[7] Roads and bridge bonds only.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

NEW YORK.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Albany	$749,000			Ontario	$176,000		
Cayuga	29,777	1–20	4½–5	Orange	689,000	30	3½–4½
Chautauqua	160,000			Orleans	156,000		4¼–5
Chemung	99,670			Otsego	60,000	10–15	4–4½–5½
Clinton	15,000		3½–4½	Putnam	38,000	15	4¾
Columbia	56,000		3½–4½	Rensselaer	465,000		3
Erie	1,297,000		3½–4½	St. Lawrence	125,000	6	4
Franklin	533,000	60	4½	Saratoga	150,000	5–14	5
Fulton	70,000		4	Seneca	62,217	10	4.7–4¾
Greene	109,500		3½–4	Steuben	60,000		4½
Herkimer	408,000			Suffolk	110,000	13½	4½
Jefferson	130,000		4	Tompkins	73,000		4
Lewis	25,244		5–6	Ulster	269,000		4–4½
Livingston	77,106	4	4½–4¾	Warren	215,000		5
Montgomery	201,000		4½	Westchester	275,660	20–25	4½
Nassau	2,007,749	6–20	{ 4–4½– 4.7–5	Wyoming	52,000		4½
Niagara	4,000			Total	9,097,923		
Oneida	150,000		5				

NORTH CAROLINA.

Alamance	$400,000		5	Iredell	$400,000		5
Anson	100,000			Jones [1]	10,000		
Beaufort [1]	[2] 125,000			Lee	100,000	40	5
Bertie	20,000		5	Lincoln	200,000	40	5
Brunswick	40,000			McDowell	9,273	5–10	6
Buncombe	50,000		5–6	Madison	300,000		
Cabarrus	[3] 145,000	30		Mecklenburg	300,000		
Cherokee: Marble District	187,000			Nash and Edgecombe Rocky Mt. District	30,000	30	6
Cleveland	60,000	40	6	New Hanover	550,000	25	4–4½–5
Cumberland [1]	40,000		5	Orange	250,000		
Davie	175,000			Pasquotank	10,000		
Edgecombe	16,000		6	Polk	[4] 100,000	30	5½
Districts 1–5, 8–11	200,000	55	5	Rutherford	250,000	40	5
Gaston	300,000		4	Sampson	150,000	10–20	5
Granville	160,000	20	4½–5	Stokes [1]	35,000	30	6
Guilford	300,000		5	Vance	220,000	20–40	5
Haywood	60,000			Yancey	150,000		
Henderson	49,000						
Hoke	50,000		5	Total	5,541,273		

NORTH DAKOTA.

Rolette [1]	$20,000		5	Stutsman	$36,500		6
Stark	6,500						
				Total	63,000		

[1] Bridge bonds only.
[2] By act of legislature, county commissioners have authority to sell bridge bonds without vote of people.
[3] Also 10 steel bridges.
[4] By act of legislature.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

OHIO.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Adams	$181,300	15	3½–6	Lucas	$1,212,437	([6])	4–4½
Ashland	[1] 258,500	10–18	4–5	Madison	132,250	10	5
Ashtabula	[2] 309,500		4½–5	Mahoning	1,408,108		4–4½
Athens	300,000		5	District 1	150,000	25	5
Auglaize	[3] 78,000	13–26	5	Marion	876,175		4–4½–5
Belmont	94,800			Mercer	2,134,600		4–5–5½
Butler	96,000			Miami	[9] 1,047,000		5–6
Champaign	23,750			Montgomery	477,000		4–4½–5
Clark	257,662		4–5–7	Morgan	40,000		4
Clermont	110,200		4–4½–5	Morrow	251,728		
Columbiana	300,000			Muskingum	[10] 920,000		5
Coshocton	[4] 150,000	10	4½–5	Noble	48,000		
Crawford	8,000		4–6	Ottawa	82,000		5–6
District 1	250,000			Paulding	847,972	7	5
Cuyahoga	6,274,524		4–4½–5	Perry	45,000	10	5
Darke	223,500		4–4½	Pickaway [7]	324,000		5
Defiance	[5] 191,000	([6])	4–4½–5–6	Pike	69,500	3–10	5
Delaware	540,544		4–4½	Portage	224,600		4–4½
Erie [7]	59,500		4	Preble	11,160		
Fayette	[8] 909,000		5	Putnam	464,600	9	5
Franklin	513,260			Richland	205,500		4½–5
Fulton	204,400	5	4½	Ross	131,000	25, 30	5
Gallia	542,000	2–20	4–4½–5	Sandusky	195,998	5	4½–5
Geauga	20,000		4½–5	Scioto	[11] 740,000	5	4–8
Greene [7]	41,000		4	Seneca	244,000		4½
Hamilton	917,650			Shelby [7]	17,000		
Hancock	408,000			Stark	[12] 605,000	5–15	5–6
Harrison	10,000		4½	Summit	509,050		4½–5½
Henry	937,250	5	5	Trumbull	[13] 905,000		4½–5–5½
Highland	7,850	5	5	Tuscarawas	130,000	1–3	6
Hocking	50,000		4½	Union	[14] 284,600		
Huron	6,500	([6])	4½–5	Van Wert	508,260	12–21	4–4½–5
Jackson	500,000			Warren [7]	284,000	1–30	4–5
Jefferson	50,000			Washington [7]	190,000	1–22	5–5½
Knox	61,000		4–5	Wayne [7]	20,000		
Lake	278,000	20	4–4½–5	Williams [7]	20,000		4½–5
Lawrence	555,000		4½–5	Wood	[15] 2,072,000	5	4½–5–6
Licking	701,000	5–15	4–5–5½–6	Wyandot	180,400		4½
Logan	30,000		4–4½	13 Districts	7,200	10	5
Lorain	598,000	18	4–5				
District 1	180,000	13	5	Total	35,241,828		

OKLAHOMA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Carter [7]	$200,000			Nowata	$100,000	25	5
Choctaw	120,000		5	Okfuskee [7]	100,000	20	5
Coal [7]	35,000			Osage	100,000		
Creek [7]	200,000	10–25	5	Pottawatomie	109,000		5–5½
Delaware	26,000		5–6	Tulsa	75,000		5
Grady [7]	60,000	20	5	Wagoner	75,000		
Johnston [7]	100,000		5				
Muskogee	140,000		5	Total	1,440,000		

OREGON.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Clatsop	$400,000	20	5	Multnomah	$1,250,000	1–30	5
Jackson	500,000	10–30	5				
				Total	2,150,000		

[1] Of this amount $114,000 bridge bonds.
[2] Of this amount $75,000 flood bonds were issued without a vote.
[3] Of this amount $70,000 for bridges.
[4] Emergency road and bridge bonds.
[5] Of this amount $65,000 used for bridges.
[6] Serial.
[7] Bridge bonds only.
[8] Of this amount $9,000 used for bridges.
[9] $60,000 issued under emergency act of 1913 for bridges.
[10] Of this amount $775,000 used for bridges.
[11] Of this amount $440,000 were 5 per cent flood emergency bonds.
[12] Bridge $250,000.
[13] Bridge $85,000.
[14] Emergency bonds.
[15] Bridge, $6,000 emergency.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

PENNSYLVANIA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Allegheny	[1]$15,900,000	30	$3\frac{1}{4}$–4–$4\frac{1}{4}$	Luzerne	[3]$2,690,000	30	$4\frac{1}{2}$
Beaver [2]	555,000	2–12	$3\frac{1}{2}$–4	Lycoming	382,900		3–$3\frac{1}{2}$–4
Bedford	9,500			Mifflin	55,000		4
Berks	475,000	2–12	$3\frac{1}{2}$	Montgomery	725,000		$3\frac{1}{2}$–4
Butler	20,000		4	Northampton	300,000		3
Cameron	1,000			Potter	25,000		5
Carbon	50,000	5	4	Susquehanna	15,000		5
Clinton [2]	202,500		$3\frac{1}{2}$–4	Venango [2]	282,000		
Columbia	86,000		4	Washington	1,789,000	5–20	$4\frac{3}{4}$
Forest	10,500		5	Westmoreland	250,000	20	$4\frac{1}{2}$
Indiana	35,800			Wyoming [2]	72,000		$3\frac{1}{2}$–4
Lackawanna	450,000	15	4–$4\frac{1}{2}$	York	103,000		
Lebanon	29,850						
Lehigh	325,000			Total	24,839,050		

SOUTH CAROLINA.

Dillon	[4] $100,000		5	Oconee	$45,000		
Horry	10,000			Richland [2]	75,000		
Kershaw [2]	40,000			Sumter	50,000		
Laurens	50,000	30	$4\frac{1}{2}$				
Marion	40,000		$4\frac{1}{2}$	Total	410,000		

SOUTH DAKOTA.

Pennington [2]	$44,000			Stanley [5]	$33,300		
				Total	77,300		

TENNESSEE.

Anderson	$300,000		$4\frac{1}{2}$–5	McMinn	$325,000		5
Benton	200,000			Madison	500,000		4
Blount	300,000		5	Marion	170,000		$4\frac{1}{2}$–5
Bradley	216,000	25–30	5	Maury	175,000		
Campbell [6]	4,000	1		Monroe	300,000		
Districts 1–5	200,000		$4\frac{1}{2}$–5	Montgomery	120,000	30	5
Carter	72,944		5	Morgan	50,000		
Elizabeth	65,000			Perry [6]	19,000	7	5
Claiborne	70,000			Polk	405,000	15–30	5–6
Cocke	300,000		5–6	Putnam	250,000	30	$4\frac{1}{2}$
Coffee	4,154			Roane	365,000	20–30	4–5
Cumberland	40,000		5	Robertson	450,000		4
Davidson	250,000		4	Sevier	245,500	15	$4\frac{1}{2}$–5
Dickson	250,000	30	5	Shelby	2,792,000	12	5
Grainger	100,000		5	Sullivan	530,000	20–30	$4\frac{1}{2}$–5
Greene	800,000	30	5–6	Sumner	200,000	30	$4\frac{1}{2}$
Hamblen	325,000	40	5	Union	50,000		4
Hamilton	65,000			Warren	168,000		
Hawkins	220,000	65	5	Washington	60,000		
Hickman	80,000	1–$12\frac{1}{2}$	$5\frac{1}{2}$	Wayne [6]	47,700		6
Jackson	250,000			White	90,000		
Jefferson	150,000	30	5				
9 districts	395,000	25	$4\frac{1}{2}$–5	Total	12,474,298		
Knox	255,000						
Loudon	150,000	30	5				
5 districts	100,000		5				

[1] Of this amount $550,000 bridge bonds.
[2] Bridge bonds only.
[3] Bridge $100.000 payable serially, last 10 years of term.
[4] Concrete bridge, $17,500.
[5] Certain townships only.
[6] Bridge bonds.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

TEXAS.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Anderson	$150,000	20	5
Atascosa	20,000		3
Austin: Districts 1–3	175,000	5–40	5
Bastrop: Districts 1 and 2	180,000	20–40	5
Baylor	100,000	40	5
Bee	49,922	20	5
Bell	19,960		5
2 districts	200,000	40	5½
Bexar	1,250,000		
Borden	7,900		4–5
Bosque: District 7	40,000	40	5
Bowie	250,000		5
Brazoria	450,000	34	4–5
Brooks	45,000	40	5
Brown: District 1	150,000		5
Burnet	47,000		
Caldwell	240,000		
Calhoun: Districts 1 and 2	235,000	40	5
Callahan	1,276		4
Cameron: District 1	20,000		
Cass: District 7	35,000	40	5
Chambers	168,000	20	5
Childress	25,000		4–6
Coke	25,000		
Colorado	60,000	40	4
Collingsworth	14,888	5–40	4–6
Collin	450,000		
Comal	153,000	40	4–4½–5
Concho [1]	15,000		4–6
Cooke	1,990		
District 1	100,000	40	5
Culberson	50,000	40	5
Dallas	1,390,000		4½
Denton: District 1	75,000	40	5
Dewitt	31,998		
Dickens	11,500	20–40	5
Dimmit	30,000		
Ellis	800,000		
El Paso	617,000	40	4
Falls	100,000		3
Fannin	1,900		4
Fayette	69,500		5
Fisher	19,900		4
Foard	83,000		3½–5
Fort Bend	420,000		4–5
Franklin	500	2–50	4½
Freestone: District 1	50,000		5
Frio	86,953	40	5
Galveston	1,500,000	40	5
Garza	50,000	40	4
Gonzales: District 1	160,000		5
Grayson: Districts 1 and 2	685,000	2–50	4½
Gregg	50,000		
Grimes	134,000		4–5
Guadalupe	239,500	30–40	4–4½–5
Hall	65,000		2
Hamilton	22,994	5–20	4–6
Hardeman	43,500		4
Hardin	169,000		5
Harris	1,508,000		
Haskell [1]	16,000		
Hays: District 1	87,000		5
Hemphill	10,000		6
Hidalgo	100,000		
Hill	102,000	40–45	3½–5
Precinct 1	250,000	40	5
Hood	36,499		4–5
Hopkins	5,963	40	6
Houston: Districts 1 and 3	174,000		5
Howard	100,000		5
Irion	20,000	40	5½
Jackson	124,500		4–5½–6
Jefferson	809,500	40	4½–5–6
Jim Wells	$125,000	10	5
Johnson	136,200		
Jones [1]	7,000	20	5
Karnes	42,000		
Kent [1]	10,000		
Kerr	40,000		
King	5,000		
Kinney	80,000		
Knox [1]	18,500		3½–5
Lamar: Justice Precinct 1	300,000	10–40	5
Lampasas [1]	45,500		4–5
Lavaca	25,000		
Leon: Districts 1, 2, 4, 5, and 6	134,000		
Liberty: Districts 1 and 4	425,000		5
Limestone: District 4	300,000	10–40	5
Live Oak	16,990		4–5
Llano [1]	25,000		
McCulloch	118,000	40	4–5
McLennan	150,000	40	3–5
McMullen	4,000		5
Matagorda	560,000		
Maverick	42,602		5
Medina	60,000	40	4
Menard	20,000		
Midland	50,000		
Milam	57,872		
Districts 2 and 5	200,000	40	
Mills [1]	5,400		
Mitchell: District 1	30,000	40	5
Montgomery: District 1	250,000	40	5
Motley	25,000		
Navarro: Districts 1 and 3	475,000	40	5
Nolan	100,000	40	5
Nueces	175,591		
Orange	200,000		5
Palo Pinto	9,750		
Parker	25,000		4
Polk	40,000	4	5
Potter	20,000		
Reeves	12,000		5
Refugio: Districts 1 and 2	50,000		4
Robertson	500,000		
Runnels	57,094		5
San Jacinto	3,000		5
San Patricio	148,000		4–5
San Saba	38,750		4
Shackleford	12,500	40	4–5
Sherman	7,000		
Smith	405,000	40	5
Somervell	16,950	20	5
Stephens	18,000		
Sterling	10,000	40	
Stonewall	50,000		4
Sutton	12,000		3½
Tarrant	1,834,000	20–25	4–5
Taylor: District 1	150,000		5
Throckmorton	2,000		
Tom Green [1]	96,000	10–40	5–6
Travis	482,000		4
Trinity: Districts 1 and 2	160,000	40	5
Upshur	149,000		
Valverde	6,000		
Victoria: District 2	200,000		5
Waller	25,000		4–5
Waller	15,000	40	5
Walker	150,000		
Ward	5,000		
Webb	10,000		6
Wharton	320,000		3–4½–5
Wheeler [1]	15,000		4

[1] Bridge bonds only.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

TEXAS—Continued.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Wichita	$15,000		
Wilbarger	75,500		4
Williamson	300,000		4½-5
Wood	150,000		5
Young	$83,996		4-5
Zavalla [1]	44,999	40	5
Total	24,960,837		

UTAH.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Boxelder	$175,000	20	4½
Cache	45,000		4
Carbon [1]	30,000	20	5
Emery	39,500		5-6
Grand [1]	8,500	20	5
San Juan	$14,500	20	
Uinta	8,000	20	5
Weber	120,000	20	4-5
Total	440,500		

VIRGINIA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Accomac: Atlantic, and Lee	$100,000		5-5½
Alleghany [1]	40,000		
Amherst	215,000	20-30	4½-5
Augusta: South River	250,000	30	5
Botetourt [1]	10,000		
Brunswick	84,000		
Charlotte	100,000		4½
Clarke [1]	90,000		4½
Culpeper:			
Catalpa	120,000	34	5
Stevensburg	45,000		5
Dickenson:			
Clintwood	54,000	2-30	
Kenady	32,000	1-30	5
Dinwiddie	105,000	20-30	5-6
Elizabeth City	30,000		5-6
Fairfax: Mt. Vernon	90,000		
Fauquier: Centre	75,000		
Fluvanna	1,300		
Giles [1]	30,000		
Greenesville	80,000		
King George	10,000		
Lee:			
Jonesville and 7 districts	440,000	6-36	5-5½
Lunenburg:			
Plymouth	40,000		5½-6
Rehoboth	24,000		5½-6
Browns Store	40,000		5½-6
Mecklenburg: 7 districts	350,000		5
Montgomery	30,000		4
Nelson	35,000		7
Norfolk	200,000		4½
Northampton: 1 district	$50,000	30	4¾-5
Orange	175,000		
Page [1]	26,000		6
Pittsylvania: Dan River	100,000	34	5
Pulaski:			
Dublin	100,000		5
Pulaski	70,000	34	5½
Rappahannock:			
Wakefield	30,000		5
Hampton	36,000		
Piedmont	28,000		
Rockingham: Plains	30,000	10	6
Russell	575,000		5
Scott:			
Esterville	100,000	20-30	5
Fulkerson	33,800		
Johnson	33,300	20-30	5
Smyth: Marion, Rich Valley, and St. Clair	325,000		5-6
Spotsylvania:			
Courtland and Chancellor	100,000	30	5
Berkeley and Livingston	100,000	30	5
Stafford	100,000		
Tazewell	625,000		
Warren: 3 districts	90,000		6
Washington	200,000		5
Westmoreland	25,000		
Wise	960,000	30	5
Total	6,632,400		

WASHINGTON.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Asotin	$35,000		
Clallam	401,000		4½-6-7
Clarke [1]	500,000		
Cowlitz	69,262		
Jefferson	133,000		5½
King	3,000,000		
Okanogan	$15,000		
Pacific	100,000		5
Snohomish	80,000	20	5
Delta	75,000		
Total	4,408,262		

[1] Bridge bonds only.

TABLE 22.—*County and district highway and bridge bonds*—Continued.

WEST VIRGINIA.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Barbour	$40,000		4	Marshall	$150,000		
Cabell	300,000		4½	Monongalia	75,000		6
Hancock:				Pleasants: St. Marys	60,000		
Baxter and Grant	225,000			Tyler:			
Butler	125,000			Ellsworth	125,000	10–34	6
Harrison	110,000			Lincoln	200,000	10–34	6
Logan [1]	60,000	20	5	Wetzel: Grant	150,000	34	6
Marion:				Wood: Parkersburg	180,000	30	4½
Fairmont	400,000	30	5				
Mannington	300,000	30	5	Total	2,500,000		

WISCONSIN.

Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and districts.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Ashland	$50,000	20	4	Sauk [1]	$40,000	20	4½
Columbia	20,000	10	4	Vilas	60,000	20	5
Florence	38,000		5				
Iron	35,000	6	4	Total	254,000		
La Crosse	11,000						

[1] Bridge bonds only.

TABLE 23.—*Township highway and bridge bonds.*

CONNECTICUT.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Fairfield:			*Per ct.*	Middlesex:			*Per ct.*
Easton	$25,000	40	3½	Chatham	$70,000		4
New Canaan	14,000		4	East Haddam	44,000	20	3½
Stamford [1]	96,000	30	4	New Haven: Derby	60,500		3¾
Wilton	35,000	20	4	New London: Mont-			
Hartford:				ville	30,000		4
Plainville	20,000			Windham:			
West Hartford	45,000		4	Brooklyn	28,000	25	4
Windsor	40,000		4	Plainfield	30,000		4
Litchfield:							
Barkhamsted	16,000		3½	Total	576,500		
North Canaan	23,000		3½				

ILLINOIS.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Adams: Melrose	$8,000			Clay: Stanford	$900		5
Bond: Central	6,000		5	Clinton:			
Bureau:				Carlyle	5,000	10	4½
Greenville	2,700		5	Germantown	3,105		4
Ohio	17,500	10	5	Santa Fe	200	8	4
Carroll:				Coles: East Oakland	15,000	5	5
Fairhaven	2,000		5	Crawford:			
Woodland	[2] 3,954		5	Honey Creek	60,000	20–25	5
Wysox	38,500	1–5	5	Hutsonville	12,000		
Champaign: Colfax	4,400	4–6	4½–5	Lamotte	58,479	20–25	5
Christian: Mount Au-				Martin	43,100		
burn	6,000		4½	Oblong	95,000	20–25	5
Clark:				Robinson	75,000		
Anderson	3,000		5	Cumberland: Green-			
Westfield [1]	2,250	6	6	up [1]	2,500		5
York	3,000		5	Dekalb: Malta	8,500	2	5

[1] Bridge bonds only.

[2] Of this amount, $1,200 for bridges.

TABLE 23.—*Township highway and bridge bonds*—Continued.

ILLINOIS—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Douglas:			
Boudre	$35,000	[1] 13	5
Sargent	35,000	2–7	5
Dupage: Naperville	2,300		
Edgar:			
Elbridge	2,500		6
Embarrass	35,000	10	5
Hunter[2]	1,500		5
Paris	35,000		5
Effingham: Mason	10,000		6–10
Ford: Button	2,500		5
Franklin:			
Browning	4,500		6
Northern	350		4
Fulton: Orion[2]	7,000		5
Gallatin:			
Bowlesville	1,000	1–2	4
Equality	4,000		6
Shawnee	7,000	1–5	4
Greene: Woodville	250		4
Grundy:			
Goose Lake	2,500		5
Maine[2]	5,500		5
Wauponsee[2]	3,300		5
Hancock:			
Appanoose	1,835		5
Hancock	6,550		5–5½
Henry:			
Alba[2]	3,500	6	5
Atkinson	5,900	10	5
Geneseo[2]	15,450	3–19	5
Loraine[2]	2,100		5
Phenix	4,250		5
Yorktown	2,500		5
Iroquois:			
Belmont	6,000		5
Chebanse[2]	4,000		5
Milford[2]	10,000		5
Pigeon Grove	5,000	10	6
Sheldon	37,500		5
Jackson:			
Carbondale	35,000	3–5	5
De Soto	7,325		6
Fountain Bluff	1,250		5
Sand Ridge	3,900		4½
Jasper:			
Grove	500		
Wade	478		
Jefferson:			
Blissville[2]	1,000		
Farrington[2]	1,000		
Jo Daviess:			
Derinda	1,500		
Elizabeth	2,500		
Pleasant Valley	10,000		5–6
Kankakee:			
Ganeer	35,000		
Momence	35,000		
Yellowhead	35,000		
Knox: Haw Creek	2,500		5½
La Salle:			
Deer Park	22,000		5¼–6
Farm Ridge	2,000		
Mission	3,750		5
Utica	26,500		5¼
Lake:			
Antioch	4,000		5
Newport	9,325	28	4–5½
Lawrence:			
Bond	6,150		6
Denison	35,000	6	5
Lee:			
Ashton	44,000	20	5
China	25,000		
East Grove[2]	3,500	20	
Lee—Continued.			
Hamilton	$12,800		5–6
Harmon	[3] 9,125		5
Viola	13,000	1–13	5½
McLean: Martin	2,200		6
Macoupin: Bird	8,000		
Madison: Godfrey	1,200		5
Montgomery:			
Hillsboro	16,000	[1] 5–8	5
Witt	2,200		6
Moultrie:			
East Nelson	3,500		5
Lovington[2]	7,375		6
Ogle:			
Maryland	4,500		5
Pine Rock	2,000	13	5
Rockvale	9,000		5
Woosung	15,000		5
Peoria:			
Jubilee	2,000		5
Logan[2]	7,000	8	5
Timber[2]	1,500		6
Pike:			
Derry[2]	3,075		5½
Fairmount	300		
Hadley	525		
Hardin	1,200		
Kinderhook	700		
Pleasant Hill	1,200		
Richland: German	1,798		6
Rock Island: Black Hawk	5,500		6
St. Clair:			
Centerville	2,500		
Fayetteville	2,000		
Freeburg	7,400	10	
New Athens[2]	8,000	12	4–5
O'Fallon	6,000		5
St. Clair[2]	3,200	4	5
Shiloh Valley	9,550	15	4–5
Saline:			
Brushy	1,500		5
Cottage[2]	1,694	3	6
Galatia	1,400		6
Harrisburg[2]	6,215		6
Independence[2]	800		6
Mountain	2,372		6
Raleigh	2,000		6
Stonefort	5,000		6
Sangamon: Salisbury[2]	6,000	5	5
Stephenson:			
Jefferson	3,000		5
Waddams	6,000		
Tazewell:			
Hopedale[2]	1,142	4	5
Mackinaw[2]	9,000		5½
Tremont	6,500		5
Vermilion:			
Grant	15,777		
Jamaica	6,500		
Middlefork	5,000		
Washington: Bolo	240		
Wayne:			
Big Mound	11,600		6
Leech[2]	4,000	5	6
Massilon	[4] 6,125	5	6
White:			
Burnt Prairie	11,000		6
Emma	25,000		5
Hawthorne	27,500		5
Mill Shoals	5,000	1–10	6
Whiteside:			
Newton	5,820	11	6
Portland	15,000	16	5
Sterling	16,000		

[1] Serial.
[2] Bridge bonds only.
[3] Of this amount, $3,000 bridge bonds.
[4] Of this amount, $3,125 for bridges.

TABLE 23.—*Township highway and bridge bonds*—Continued.

ILLINOIS—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Will:			*Per ct.*
Channahon	$5,500	...	5
Crete	35,000	13	5
Custer	3,000	3	5
Dupage	1,500	...	5
Winnebago:			
Cherry Valley	12,325	...	5
New Milford	17,725	...	5–6–6½
Winnebago—Contd.			
Roscoe	$35,000	5	5
Woodford:			6
Patridge	1,300	...	
Spring Bay	2,700	...	5
Total	1,618,634	...	...

INDIANA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Adams: Townships	$1,026,321	(2)	4½
Allen: Townships	134,132	1–20	4½
Bartholomew: Townships	780,180	10	4½
Blackford: Townships	[1] 249,063	10	4½
Benton: Townships	723,560	10	4½–6
Boone: Townships	127,150	10	4½
Carroll: Townships	1,016,686	[3] 10	4½
Cass: Townships	[1] 692,158	...	...
Clark: Townships	[1] 213,138	[3] 10	4½
Clay: Townships	1,004,354	...	4½–6
Clinton: Townships	850,000	10	4½
Crawford: Townships	71,806	...	4½–5
Daviess: Townships	934,988	[3] 1–20	4½
Dearborn: Townships	219,330	1–20	4½
Decatur: Townships	779,583	10	4½
Delaware: Townships	850,000	10	4–5
Dubois: Townships	216,400	...	4½–6
Fayette: Townships	[1] 39,609	...	4½
Fountain: Townships	425,000	10	4½–6
Franklin: Townships	173,820	10	3½–6
Gibson: Townships	808,770	10	4½–5½
Grant: Townships	760,702	10	4½
Greene: Townships	861,062	...	4½
Hamilton: Townships	525,836	...	...
Hancock: Townships	255,065	...	4½–5
Harrison: Townships	202,887	...	4½–5
Hendricks: Townships	315,846	...	4½
Henry: Townships	47,408	...	4½
Howard: Townships	736,000	10	4½
Huntington: Townships	[1] 301,289	10	4½
Jackson: Townships	[1] 230,000	...	...
Jasper: Townships	[1] 237,195	10	4½
Jay: Townships	310,828	10	4½
Jefferson: Townships	135,119	20	4½–5
Jennings: Townships	417,210	...	4½–5
Johnson: Townships	127,025	10	4½
Knox: Townships	[1] 824,496	10	4½
Kosciusko: Townships	1,440	...	...
Lake: Townships	[1] 1,766,211	...	...
Laporte: Townships	[1] 654,320	[3] 20	4½
Lawrence: Townships	[1] 384,630	10	4½
Madison: Townships	849,820	...	...
Marion: Townships	[1] 40,735	...	...
Marshall: Bourbon	[1] 28,500	15	4½
Martin: Townships	$148,870	1–12	...
Miami: Townships	504,530	10–20	4½–5
Monroe: Townships	599,465	...	3½
Montgomery: Townships	849,820	...	4½–6
Morgan: Townships	393,689	...	4½
Newton: Townships	456,125	...	4½–6
Ohio: Townships	20,078	...	...
Orange: Townships	[1] 170,541	...	...
Owen: Townships	394,089	40	4½–5
Parke: Townships	893,367	10	4½
Perry: Townships	73,000	20	4½
Pike: Townships	152,296	...	...
Porter: Townships	[1] 725,516	...	...
Posey: Townships	[1] 473,231	...	...
Pulaski: Townships	[1] 270,229	...	...
Putnam: Townships	757,005	...	4½
Randolph: Township	[1] 517,176	...	4½
Ripley: Townships	[1] 259,366	...	...
Rush: Townships	625,742	...	4½–5½
Saint Joseph: Townships	[1] 23,500	...	...
Scott: Townships	108,856	10	4½
Shelby: Townships	166,805	20	4½–6
Spencer: Townships	[1] 37,300	...	4½–6
Sullivan: Townships	1,215,564	...	4½–5
Starke: Township	[1] 254,429	...	...
Switzerland: Townships	160,019	...	4½–5
Tippecanoe: Townships	[1] 273,930	...	4½–6
Tipton: Townships	[1] 76,372	...	...
Union: Townships	79,711	...	4½
Vanderburg: Townships	[1] 137,600	...	4½
Vermilion: Townships	[1] 292,132	...	...
Vigo: Townships	601,222	...	...
Wabash: Townships	784,220	1–20	4½
Warren: Townships	[1] 402,270	...	...
Warrick: Townships	78,163	...	4½
Washington: Township	[1] 232,799	10	4½
Wayne: Townships	410,940	10	4½
Wells: Townships	[1] 473,660	...	...
White: Townships	[1] 385,680	...	...
Whitley: Townships	[1] 8,369	...	...
Total	35,837,348	...	...

[1] Outstanding Jan. 1, 1913. [2] Six months. [3] Serial.

TABLE 23.—*Township highway and bridge bonds*—Continued.

KANSAS.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				*Per ct.*
Allen: Iola	$33,000		6	Mitchell: Pittsburg[1]	$26,000		5
Barton:				Neosho: Mission	32,000		
Lakin[1]	20,000		6	Ottawa: Center	9,500		7
Liberty[1]	6,000			Pottawatomie:			
Butler: Douglass	9,000		4–4½	St. Mary's	40,000		4½
Cherokee: Shawnee	150,000			Womego	35,000		6
Cloud:				Riley: Manhattan	12,200		
Lincoln[1]	18,700	10–30	6–10	Rush: Belle Prairie	1,000		6
Shirley	1,565			Sedgwick: Payne	5,000		5
Sibbey	2,000	5	5	Wabaunsee: Kaw	9,000		5
Comanche: Township	54,000			Wilson:			
Douglas: Grant	2,500			Center	7,000		
Finney: Garden City	16,000		6	Clifton	2,100		6
Franklin: Cutler[1]	2,500			Fall River	4,900		
Geary: Junction City	89,600	9–10	5–6	Guilford	10,000		
Hamilton: Coolidge	18,000		5	Neodesha	12,000		
Kingman: Bennett	17,500	30	5½	Wyandotte: Township	5,000		
Kiowa: Glick[1]	5,000	(2)					
McPherson: Township	6,000			Total	677,065		
Marshall: St Bridget	15,000		5				

MAINE.

Kennebec: Benton	$1,500	5	4	Waldo: Frankfort[1]	$1,000		5
Knox: Vinal Haven	2,500			Washington: Jonesport	1,000	6 mos.	6
Oxford: Norway[3]	35,000	35	4				
Penobscot: Orono[1]	12,000	2–3–4	4	Total	78,000		
Piscataquis: Foxcroft[1]	25,000	1–25	4				

MASSACHUSETTS.

Barnstable:				Franklin—Con.			
Barnstable	$40,500		4	Northfield[1]	$30,000		3½
Brewster	15,000			Sunderland	2,500		4
Harwich[1]	63,400		5½	Hampden:			
Mashpee	400		4	Russell	14,000		4
Wellfleet	24,000		3½–4	Westfield	100,000	10	4
Bristol:				Hampshire: Amherst	50,000		4
Fairhaven[1]	42,000	42	4	Middlesex: Billerica	18,000		4–4½
North Attleboro	6,000	1–6	5	Nantucket: Nantucket	36,000	10	5
Somerset[1]	8,000		4	Norfolk: Millis[1]	5,856	3	4
Swansea	4,000		4	Plymouth:			
Essex:				East Bridgewater	5,000		4
Amesbury	16,000		4	Plymouth	100,517		4–4½
Marblehead	45,000		4	Worcester: Grafton	3,800		4
Franklin:							
Conway	15,000	10		Total	650,473		
Gill	4,500		4–4½				
Monroe[1]	1,000		4				

MICHIGAN.

Alcona: Mikado	$2,000		5	Benzie: Crystal Lake	$20,000		
Allegan:				Berrien: 3 townships	89,000		
Gunplain	20,000		4½	Branch: Union	10,000	5	5
Saugatuck	18,000		4½	Charlevoix: Hudson[1]	1,100		7
Antrim:				Cheboygan:			
Banks	20,000	20	5	Benton	10,000		5
Central Lake	20,000			Forest	7,000		6
Arenac: Au Gres	1,550			Walker	5,000		5
Baraga:				Chippewa:			
Arven	10,000			Sugar Isle	2,000		6
Covington	18,000			Trout Lake	10,000		
L'Anse	25,000		6	Clare: Redding	3,000		5

[1] Bridge bonds only. [2] Serial—1989. [3] For roads and sewers.

TABLE 23.—*Township highway and bridge bonds*—Continued.

MICHIGAN—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Crawford: 2 townships	$16,000		
Delta:			
Bark River	12,300	10	5
Escanaba	5,000	5	5
Ford River	3,000		5
Wells	10,000		5
Dickinson: Norway	8,000		5
Genesee:			
Davison	8,300		5½
Forest	10,000		4
Montrose	7,000	6	5
Thetford	10,000	10	5
Vienna	10,000		5
Gladwin: Bourret	3,500		5
Gogebic: Marenisco	20,000	20	7
Grand Traverse:			
Paradise	30,000		
Whitewater	24,000		
Green Lake	18,000		
Hillsdale: Fayette	3,450	1	5
Houghton: Chassell	3,000		6
Huron:			
Bingham	2,000		
Bloomfiel	2,000		6
Brookfield	15,000		5
Colfax	20,000		
Oliver	12,000		5
Sebewaing	75,000		
Windsor	50,000	10	4½
Ionia:			
Ionia	12,000		5
Lyons[1]	12,000		5
Isabella: Vernon	6,000		
Iron:			
Crystal Falls	15,000		5
Mastadon	20,000		
Kalkaska:			
Clearwater	6,000		
Cold Springs	5,000		
Springfield	9,000		
Lake:			
Ellworth	6,000		5
Newkirk	6,000		5
Leelanau:			
Empire	11,000		5
Leelanau	20,000		
Townships (3)	26,000		
Mackinac:			
Garfield	8,903		5
Hudson	4,000		
Newton	5,000		
Macomb:			
Lake	50,000		
Warren	36,000		
Manistee:			
Maple Grove[1]	1,100		7
Springdale	10,000		
Stronach	500		5
Marquette:			
Powell	30,000		
Wells	5,000		5
Mecosta: Wheatland	1,000		
Mason:			
Custer	20,000		
Free Soils	15,000		
Riverton	20,000		
Menominee: Stephenson	11,000	10	5–7
Midland:			
Edenville[1]	9,000		5
Greendale[1]	3,000		4½
Ingersoll	10,000	11	5
Jerome	6,500		
Midland—Continued.			
Larkin	$1,413		
Mount Haley	1,000		5
Missaukee:			
Butterfield	4,000		6
Clam Union[1]	800		4
Pioneer	6,000	3–9	5
West Branch	3,000		
Monroe:			
Bedford	39,000	13	5
Erie	40,000		
Ida	30,000	20	5
Whiteford	60,000		5
Montcalm:			
Eureka	725	10	5
Montcalm	1,045		5
Reynolds	10,000		5
Newaygo:			
Ensley	1,200		5
Grant	7,500		5
Groton	20,000		
Four townships	39,000		
Oceana:			
Elbridge	20,000	21	5
Golden	19,500		5
Greenwood[1]	1,267	3	6
Hart	44,250		
Pentwater	20,000		6
Shelby	14,000		5
Weare	3,000		5
Ogemaw: Cumming	5,000	20	5
Ontonagon:			
Ontonagon	10,000		5
Carr Lake	20,000		
McMillan	9,500		
Rockland	28,500		
Osceola:			
Burdell	10,000		5
Evart	14,000	20	5
Hartwick	8,000		5
Hersey[1]	6,000		5
Lincoln	5,000		5
Marion	12,000		5
Osceola	25,000	15	5
Otsego: Hayes	600		7
Ottawa: Robinson	8,000	16	5
Presque Isle: Allis	2,800		5
Roscommon:			
Gerrish	15,000		5
Richfield	18,500	25	5
Saginaw:			
Blumfield	10,000		4
Bridgeport	20,000		
Maple Grove	10,000		4½
Richland	20,000		4½
St. Charles	10,000		5
Spalding	5,000		4½
St. Clair:			
East China[1]	3,000		5
Kimball	25,000		4
Sanilac:			
Forrester	5,000	10	5
Wheatland	5,000	5	5
Schoolcraft:			
Hiawatha[1]	4,000		6
Mueller	6,000	9	5
Tuscola:			
Ellington	3,832		6
Fairgrove	20,000		
Wellington	4,500		
Van Buren:			
Covert	25,000	5	5
South Haven	25,000	5	5
Washtenaw: Salem	5,000		

[1] Bridge bonds only.

TABLE 23.—*Township highway and bridge bonds*—Continued.

MICHIGAN—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Wayne: Redford	$50,000	20–30	4½
Wexford:			
Antioch	2,000		5
Cherry Grove	5,000		
Greenwood	5,000		5
Wexford—Contd.			
Henderson	$2,000		
South Branch	2,000		5
Total	1,926,135		

MINNESOTA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Aitkin:			
Cornish	$6,000		4
Fleming	1,200		4
Haugen	7,000		4–6
Hebron	3,500		6
Jevne	4,000	20	4
Jewett	3,500		6
Pequadna	3,000		6
Pliny	4,000	19	4
Verdon	1,000		6
Wagoner	5,000		4
Wealthwood	7,300		6
Williams	7,000		4
Workman	5,000		6
Becker: Spring Creek	1,500		4
Beltrami:			
Eland	2,000	6	4
Kelliher	7,000		6
Wabanica	3,500		4
Benton:			
Alberta	1,100		
Longola	3,000	[1] 18	4
Watab	1,500		6
Bigstone: Otrey	2,150	5	6
Brown: Prairieville [2]	2,000		6
Carlton:			
Barnum	2,200	15	5
Beseman	8,000		6
Blackhoof	3,000	15	4
Carona	1,500		
Eagle	3,000		4
Holyoke	10,000	15	6
Kalavala	3,000	15	4
Knife Falls	3,000	10–15	7
Lakeview	9,603	20	6
Mahtowa	3,000	20	4
Red Clover	3,500	13	4
Split Rock	3,000	13	4
Chippewa:			
Crate	5,000	5–20	4
Lone Tree [2]	3,000	20	3
Chisago:			
Rushseba [2]	600	7	6
Sunrise [2]	5,000	6	4
Clay:			
Felton	6,500		4
Flowing	1,000		6
Morken	4,500	19	10–7
Cook:			
Colvill	12,000		6
Grand Marais	15,000		6
Hovland	20,000	(1)	6
Maple Hill	15,000		6
Schroeder	8,000	14	7
Cottonwood: Rose Hill [2]	2,000		4
Crow Wing: Littlepine	3,000	5	4
Dakota:			
Randolph [2]	2,360		5–6
Waterford [2]	2,500	4	5
Dodge: Ashland	2,650	1	6
Douglas: Belle River	2,300		5–7
Fillmore: Pilot Mound	7,500		6
Goodhue:			
Central Point [2]	$500		5
Vasa [2]	4,800		5
Houston: Yucatan [2]	2,500	5	5
Hubbard:			
Alice	3,000	[1] 10	4
Badoura	200		4
Farden	1,200	10	4
Guthrie	1,000	6–10	4
Hart Lake	1,000		4
White Oak	3,000	5–20	4
Isanti: Stanford [2]	500		
Itasca:			
Alvwood	2,000	5	4
Ardenhurst	3,500		4
Balsam	20,000		6
Bass Brook	15,000	4–15	5½
Bigfork	8,000	20	6
Deer River	12,000		6
Feeley	3,000	20	6
Grand Rapids	10,650		5
Marcell	10,000	20	6
Trout Lake	8,500	3–21	6
Jackson:			
Enterprise [2]	3,000		4
Sioux Valley	3,600		4
Kanabec:			
Kroschel	3,400		4
Pomrey	4,100	11	4
South Fork	1,500		4
Hillman	3,000	10	4
Kandiyohi: Lake Elizabeth	550		
Kittson:			
Davis	1,000	10	6
Hallock	12,300		4–7–10
Percy	3,500		4½
Red River	1,100	10	7
St. Vincent	3,000		4
Spring Brook	1,400	5–11	4
Svea	1,000		4
Teien [2]	6,000		4
Thompson [2]	7,800		4
Koochiching:			
Bannock	3,000	10	4
Cingmare	12,000		6
Dinner Creek	3,000		4
Englewood	2,000	[1] 1–20	4
Forest Grove	2,000	6–16	4
Grand Falls [2]	1,500	10	6
Jameson	10,000	20	6
Koochiching	15,000		6
Lindford [2]	3,000	12	4
Meding	7,000	10	4
Pine Top	5,000	10	6
Reedy	6,000	10	4
Sturgeon River	3,000		6
Wildwood	8,000	4–11	6
Lac Qui Parle:			
Mehurin	2,400		4
Ten Mile Lake	50,400		4
Lake:			
Two Harbors	2,500		
Waldo	3,500		4

[1] Serial.

[2] Bridge bonds only.

TABLE 23.—*Township highway and bridge bonds*—Continued.

MINNESOTA—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Lincoln: Diamond Lake	$500		
Lyon: Eidsvold [1]	1,025		8
McLeod:			
Collins	3,000		4
Rich Valley	1,000		6
Mahnomen:			
Beaulieu	1,000		4
Bejou	1,500	20	
Heier	1,000		4
Townships	6,600		
Marshall:			
Alma	1,200	5–9	4
Big Woods	1,400	5	8
Donnelly	1,000	10	7
Lincoln	6,000	20	6
Vega	1,300		4
West Valley	1,000	20	4
Millelacs:			
Bogus Brook [1]	2,200		4
East Side	1,500		4
Kathio	12,000	20	4
Onamia	4,000		4
Page	7,000	9	4
South Harbor	3,000	([2])	4
Morrison:			
Hillman	4,000	14	4
Rosing [1]	800	6–13	6
Murray: Des Moines River	1,200		4
Nicollet: Belgrade	4,000		6
Nobles. Townships	5,700	10	4
Norman:			
Anthony [1]	500		4
Good Hope	3,000		6
Hegne	800	5–10	10
Olmsted: Rochester	1,769		4½
Ottertail:			
Buse [1]	1,058		6
Eagle Lake	400		
Maine	2,000		4
Paddock	1,000		
Pennington:			
High Landing	3,000		6
Rocksbury	1,500	10	10
Pine:			
Arna	2,000		5
Brookpark	5,540		4
Bruno	14,000		5½–6
Chengwatana [1]	3,000		4
Danforth	4,000		4
Fleming	10,000	13	6
Kettle River	3,600		
Mission Creek	5,000		6
Partridge	9,500		6
Pine City [1]	2,400	6–13	4
Pokegama	1,700	10	4
Rockcreek	1,600		4
Wilma	2,500		4
Pipestone: Sweet	2,500		4
Polk:			
Fairfax	3,500	5–15	4
Farley	12,000	5	4
Gentilly	1,000		4
Nesbit	5,000	20	6
Sandsville	1,000	10	10
Sullivan	14,000		4–10
Tabor	1,300		6
Pope: New Prairie [1]	$800		6
Ramsey: White Bear	12,500		4
Red Lake:			
Lake Pleasant	1,000		
Terrebonne	1,700		5
Redwood:			
Brookville	3,000	5–10	4
Sundown	4,000		7
Renville: Crooks	2,500		5
Rice:			
Bridgewater [1]	3,000		5
Flora	2,000	5	4
Rock:			
Denver	1,600		6
Kanaranzi	3,500		6
Luverne	2,500		6
Springwater [1]	8,000		6–8
Roseau:			
Cedarbend	1,700		4
Deer	4,000	20	6
Dieter	9,500		6
Grimsted	6,000		
Jadis	6,000		6
Lind	1,600		4
Malung	1,000		6
Mickinock	6,600		6
Moose	8,600		6–7
Pohlitz	5,000		6
Ross	10,000	10	6
Spruce	5,000		6
Stafford	5,900	5	4–6
Stokes	9,500	20	6
St. Louis:			
Ault	6,000		6
Beatty	3,000		4
Canosia	10,000		10
Clinton	3,000	10–15	6
Mesaba	15,000		5½
Scott: Belleplaine	1,500	3	5
Sherburne:			
Elk River	5,000		6
Livonia	1,000		4
Talmer	2,400		5
Sibley: Dryden	1,000		
Stearns:			
Brackway	1,500		4
Grove	1,800		6
Paynesville	3,000		4½
Steele: Lemond	1,400		6
Stevens: Baker	850		
Todd: Little Elk	5,000	7–16	4
Wadena:			
Bullard	1,500	([2])	4
Huntersville	2,500		
Orton	3,000		4
Wing River [1]	1,900	9	4
Washington: Newport	20,000		5
Watonwan; Adrian	3,000	[2] 5	5
Wilkin: Andrea	2,000		5
Wright: Townships	3,000		4
Yellow Medicine:			
Oshkosh [1]	4,000		4
Wright	3,000		
Total	982,805		

[1] Bridge bonds only. [2] Serial.

TABLE 23.—*Township highway and bridge bonds*—Continued.

MISSOURI.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
Nodaway:			
Polk	$50,000		
Union	15,000	[1]	6
Total	65,000		

NEBRASKA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.				
Dawson: Lexington	$6,000			Platte—Continued.			*Per ct.*
Keith: Ogallala	26,670			Loup	$3,000	15	6
Lincoln:				Oconee [2]	6,000	15	6
Bostwick	4,000			Scotts Bluff:			
Hershey	20,000			Castle Rock and			
Merrick: Loup	3,000			Highland	12,000		
Morrill: Township	14,000			Gering	10,000	20	5
Nance:				Winter Creek	15,000		
Genoa	82,500	20	6				
Township	14,000			Total	246,170		
Platte:							
Columbus	30,000						

NEW HAMPSHIRE.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
Grafton: Bristol	$15,000		3
Merrimack: Hookset [3]	25,000	20	4
Total	40,000		

NEW JERSEY.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Atlantic:			*Per ct.*	Camden:			*Per ct.*
Egg Habor	$95,000	8–13	4½	Delaware	$7,000		5
Hamilton	97,000			Gloucester	6,000		5
Bergen:				Haddon	2,900		5
Franklin	75,000		4	Voorhees	2,500		5
Hillsdale	45,000	5	5	Cape May: Lower	5,000		5
Hohokus	22,000		4½–5	Essex: Belleville	87,000		4
Midland	30,000		5	Gloucester:			
Orvil	7,000		5	Monroe	500		5
Overpeck	75,500		5	Wollwich	3,900		5
Riverdale	25,000	31	5	Hunterdon: West			
Union	42,500	30	4	Amwell	4,900		4½
Washington	14,500		5	Monmouth: Neptune	23,000		4½–5
Burlington:				Salem: Upper Pitts-			
Chester	40,000		4½	grove	800		5
Northampton	15,000	30	4	Union: Cranford	8,600		5
Pemberton	10,000		4½				
Southampton	15,000	30	4½	Total	760,600		

[1] Serial bonds. [2] Bridge. [3] Bridge bonds.

TABLE 23.—*Township highway and bridge bonds*—Continued.

NEW YORK.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Allegany:			*Per ct.*
Angelica	$9,000		
Scio	5,000		
Chautauqua:			
French Creek	3,000	3	4½
Kiontone	4,000	4	
Westfield	28,000		4
Chemung:			
Big Flats	40,645		4½
Chemung	20,000		4½
Elmira	3,408		4½
Cortland:			
Cortlandville	14,000		
Homer	4,000		
Marathon	4,800		
Delaware:			
Middletown	6,000		
Sidney	1,400		
Essex:			
Chesterfield	1,500		
Keene	5,500		
Lewis [1]	6,500		
St. Armand	4,000		
Franklin:			
Bombay	3,000		
Malone	8,000		
Moira	7,000		
Fulton: Caroga	35,000	6	5
Genesee: Le Roy [1]	12,000		
Hamilton: Long Lake	30,000		
Herkimer:			
Frankfort	2,765	4	5½
German Flats	6,000		
Herkimer	88,232	11	4½
Manheim	25,771	12	4½
Newport [1]	12,500	16	4
Russia	3,000		
Salisbury	5,900	5	5
Schuyler	12,530		
Webb	17,000	19	5
Jefferson:			
Clayton	18,000		
Ellisburg [1]	24,000		
Henderson	9,000		
Lyme [1]	25,000		
Jefferson—Contd.			*Per ct.*
Philadelphia	$8,000		
Rutland [1]	6,000		
Lewis:			
Denmark	6,000	6	5
Lowville [1]	9,000		
Oneida:			
Augusta	10,000		
Kirkland	11,500		
Paris	5,000		
Vernon	20,000		
Otsego:			
Maryland	3,000		
Unadilla	5,500		
Westford	2,500		
Putnam: Putnam Valley	25,000	12	4¼
Schenectady: Princetown [1]	1,200	1–4	6
Seneca: Lodi	1,200		
Steuben:			
Canisteo	1,000		
Corning	13,000	2–5	5
Rathbone	2,480		
Suffolk:			
East Hampton	70,000	6–20	4
Huntington	17,703		
Babylon and Southampton	80,000		
Tompkins:			
Lansing [1]	5,000	(2)	4½
Trumansburg	25,000		
Westchester:			
Bedford	5,517	6–19	4–5
Cortland	196,393		
Eastchester	259,000		4–5
Greensburg	357,500		4
Harrison	310,600		4–4½
New Castle	145,693		
North Castle	4,578		
Pelham	18,000		
Rye	135,000		
Scarsdale	147,350		
White Plains	218,000		
Total	2,631,165		

NORTH CAROLINA.[3]

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Alleghany: Township	$50,000		
Anson: Wadesboro	2,000		
Ashe: Horse Creek	5,800		
Bertie: Township	5,000		
Bladen: Township	10,000		
Brunswick:			
Smithville	35,000		5
Towncreek	15,000	20	5
Buncombe: Black Mountain	20,000		
Burke: Morganton	50,000		
Caldwell: Lovelady	25,000		
Carteret:			
Morehead	10,000	42	5
Newport	3,000	42	5
Catawba:			*Per ct.*
Hickory	$50,000		
Newton	50,000		
Cherokee:			
Murphy	50,000	20	6
Valley Town	47,000		5½–6
Cleveland:			
Kings Mountain	25,000	30	5
Shelby	50,000	15	5
Townships 6 and 7	50,000		
Davidson: Lexington	100,000		
Duplin:			
Calypso	5,000		
Faison	15,000		
Rosehill	20,000		

[1] Bridge bonds only.
[2] Serial.
[3] By act of legislature, county commissioners have authority to sell bridge bonds without vote of people.

TABLE 23.—*Township highway and bridge bonds*—Continued.

NORTH CAROLINA—Continued.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Duplin—Continued.			
Wallace	$5,000		
Warsaw	20,000		
Franklin:			
Franklinton	140,000	30	5–5½
Louisburg	70,000		5½
Youngsville	55,000		6
Greene: 7 townships	180,000		
Halifax:			
Enfield	60,000		
Halifax	40,000		
Haywood: Waynesville	50,000		5
Henderson:			
Edneyville	12,000		
Hendersonville	50,000		
Hoopers Creek	20,000		
Jackson:			
Cullowhee	30,000		
Dillsboro	15,000		
Lee	15,000		
Sylva	30,000		
McDowell:			
Marion	50,000		6
Nebo	10,000		6
Old Fort	20,000		6
Macon: Franklin	100,000		
Madison: 2 townships	20,000		
Martin:			
Robersonville	50,000		
Williamston	40,000		
Moore:			
Carthage	8,000		6
Deep River	12,500		
Greenwood	10,000		
McNeills	14,000	10–30	5–5½
Moore—Continued.			
Mineral Springs	$10,000		
Sand Hill	10,000		6
Nash:			
4 townships	40,000		
Manning	50,000		
Onslow: Jacksonville	10,000		
Orange: Hillsboro	40,000		
Pitt: Greenville	50,000	40	5
Polk: Tryon	12,000		
Richmond:			
Beaver Dam	10,000		
Black Jack	5,000		
Marks Creek	15,000		
Mineral Springs	5,000		
Rockingham	25,000		
Steeles	15,000		
Wolfs Pitt	25,000		
Scotland:			
Laurel Hill	30,000	30	4
Spring Hill	20,000		4
Stewartsville	50,000		
Williamson	30,000		
Stokes:			
Danbury	15,000	30	6
Meadows	40,000	30	6
Sauratown	50,000	30	6
Surry: Mount Airy	85,000	30	5
Warren: Warrenton	50,000		
Wayne:			
Brogden	40,000		
Goldsboro	100,000		
Wilson: Wilson	100,000		
Total	2,751,300		

OHIO.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Adams: Wayne	$7,000		4
Ashland:			
Montgomery	[1] 98,000		
Sullivan	25,000	10–18	5
Troy	70,000	10–18	5
Athens:			
Canaan	1,000	2–4	5
Trimble [2]	20,000		
Belmont:			
Colerain	25,000		
Pease	88,000		5
Pultney	25,000		
Warren	33,000		
Washington	40,000		
York	32,000	16	5
Columbiana:			
Perry	25,000	(3)	5
St. Clair	20,000	23	5
Crawford: Townships	355,500	8–20	4–6
Cuyahoga:			
Bedford	33,500		5–8½
Brecksville	19,000	15	4½
Brooklyn	7,000	10	5
Dover	35,829		4½
Euclid	32,161	24	4½
Independence	5,000		4½–5
Mayfield	8,500		4½
Olmsted	30,500		4½
Orange	32,600		4½
Parma	16,000		4½
Rocky River	30,900	8–16	4–4½–5
Royalton	19,725		4½–5
Solon	14,000		4½
South Newburgh	35,500		5
Strongsville	10,500	1–8	4½
Cuyahoga—Contd.			
Warrensville	10,000		
West Park	5,000		
Erie: Groton	25,000		4½
Fulton: 12 townships	392,200		5
Geauga: Hambden	3,000	6	4
Hamilton: Springfield	17,500		4½
Harrison:			
Short Creek	9,000		5
Stock	2,700		4–6
Henry: Ridgeville	2,500		6
Huron:			
Bronson	15,500	(3)	5
Greenfield	4,800	(3)	6
Greenwich	64,000	(3)	4½
Lynne	28,000	(3)	4½–5
New Haven	50,000	5	4½
New London	40,000		4½
Norwalk	25,000		
Norwich	46,000		4–5
Peru	15,000	(3)	4½
Richmond	31,000		6
Ridgefield	35,000		5
Sherman	40,000	10	5
Wakeman	27,500		4–4½
Jefferson: Springfield	25,000	29	4½
Knox: Hillar	10,000		
Lake:			
Painesville	7,500		6
Willoughby	38,000		4½
Lorain:			
Brighton	14,000		5
Columbia	24,000		4½
Grafton	40,000		5
Huntington	11,500		5
Rochester	20,000		4½

[1] Flood bonds issued without vote. [2] Bridge bonds. [3] Serial.

TABLE 23.—*Township highway and bridge bonds*—Continued.

OHIO.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Lucas:			
Monclova	$8,000		5
Springfield	2,000	2	6
Mahoning:			
Canfield	100,000	25	4½–5
Ellsworth	18,500		4½
Poland	115,000		4½
Smith	100,000		4½
Springfield	90,000		
Marion: Tully	40,000		
Medina:			
Brunswick	22,500		5
Guilford	64,000		4½
Hinckley	20,600	20	5
Liverpool	19,000	12	5
Medina	127,500		4½
Miami:			
Brown	1,200	(1)	5
Concord	7,000		
Newberry	2,000		5
Montgomery:			
Clay	30,000	5	5
Van Buren	10,000		5
Noble:			
Caldwell	6,000	15–19	6
Noble	20,000		4–5
Olive	20,000		5
Ottawa:			
Allen	37,000		
Bay	24,450		5
Catawba	20,000		5
Danbury	25,200		5
Erie	22,000	7–15	5
Harris	45,200	25	5
Perry: Coal	19,000		6
Pickaway:			
Derby	17,000		
Jackson	18,000		
Portage:			
Aurora	4,000		
Brunfield	6,900		
Ravenna	9,000	2–10	4
Richland:			
Cass	35,000		4½–5
Plymouth	61,000		5
Sharon	50,000		5–6
Weller	42,000		4–5
Sandusky:			
Ballville	12,000		4
Madison	3,100		4½
Scioto: Porter	$10,000	9–19	4½
Seneca:			
Adams	10,000	10	5
Big Spring	60,500		4½
Bloom	72,500	10	4½
Eden	66,000	13	4½
Hopewell	38,000		4½
London	11,000		
Scipio	27,000		4
Seneca	47,000		4
Stark:			
Canton	26,000		5
Lexington	10,000		4
Sugar Creek	14,000		5
Washington	4,000		5
Summit:			
Coventry	10,000		
Hudson	10,000		4½
Richfield	5,000		5
Stowe	8,000		4½
Twinsburg	7,000		4½
Trumbull:			
Bristol	3,000		6
Fowler	10,000		5
Liberty	100,000		5
Lordstown	100,000	3	4
Newton	47,500		
Vienna	25,000		5
Tuscarawas:			
Mill	10,000	5	5
Perry	1,200	3	5
Van Wert:			
Harrison	125,000	25	4–4½
Jennings	21,000		4
Liberty	144,000		4–4½
Pleasant	131,000		4–4½
Ridge	125,000		4–5
Tully	75,500	23	4–5
Willshire	140,000		4
York	110,000		
Vinton: Vinton	540		4
Williams: Brady	35,000		4½
Wood: Liberty	50,000	5	4–5–6
Wyandot: Tymochtee	46,000	10	4½–5
Total	5,283,805		

OKLAHOMA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Carter:			
Berwyn	$15,000	15	6
Morgan	40,000		
Wilson	10,000		
Creek: Sapulpa	50,000	20	5
Kay: Miller	18,000		
Osage:			
Bigheart	50,000		
Big Hill	50,000		
Strike Ax	50,000		
Rogers:			
Catoosa	$3,000	25	6
Verdigris	14,288	25	6
Stephens: King	27,500	15	6
Tulsa: Red Fork	50,000		
Wagoner: Stonebluff	4,500		
Total	382,288		

[1] Serial.

TABLE 23.—*Township highway and bridge bonds*—Continued.

PENNSYLVANIA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per ct.
Allegheny:			
Mifflin	$18,000	20	5
Reserve	21,000	....	4½–5
Scott	10,000	8	4½
Stowe	20,000	....	4½
Union	13,000	....	5
Versailles	3,500	....	5
Armstrong:			
East Franklin	4,300	17	4½
Kiskiminetos	5,500	20	5
Manor	5,000	....	5
Beaver:			
Big Beaver	5,000	9	5
Chippewa	1,850	....	6
Dougherty	5,412	....	6
White	1,000	4	6
Bedford:			
Bloomfield	4,000	5	4
Liberty	400	....	4
South Woodbury	9,500	4–10	4–5
Berks:			
Alsace	800	....	....
Richmond	1,500	1	5
Blair:			
Greenfield	5,800	....	4½
Logan	35,000	....	5
Taylor	4,500	20	4½
Bradford:			
Armenia	385	3	5–6
Terry	450	....	....
Warren	800	1	4
Bucks:			
Bristol	38,333	....	4
Middletown	50,000	....	4
Southampton	50,000	....	4
Butler:			
Adams	3,000	6	5
Butler	5,500	15	4½
Cambria: Middle Taylor	1,250	....	6
Cameron:			
Grove	1,600	8	6
Lumber[1]	2,200	3	5–6
Shippen	8,000	10	6
Carbon: Penn Forest	3,800	....	5–6
Center:			
College	2,000	....	5
Gregg	900	....	5
Haines	500	....	5
Half Moon	700	....	4½–5
Chester:			
East Brandywine	2,100	....	4–5
East Coventry	7,200	....	4½
East Goshen	34,500	....	4
New Garden	7,200	30	5
New London	2,000	....	5
Penn	3,000	....	5
Pennsburg	11,000	....	5
Tredyffrin	12,000	9	4½
Valley	2,300	....	5
West Brandywine	2,000	....	4½
West Calm	5,000	....	5
West Goshen	2,500	....	4½
Willistown	40,000	....	4
Clarion: Licking	400	....	6
Clearfield:			
Bell	5,000	....	5
Burnside	2,000	5	5
Cooper	1,000	....	6
Decatur	5,000	....	5
Ferguson	500	....	....
Gulich	3,795	....	....
Jordan	750	....	....
Lawrence	4,900	....	5½
Penn[1]	2,000	....	....
Clinton:			
Dunnstabler	1,400	....	5
Clinton—Contd.			
Leidy	$12,500	10	5
Logan	150	....	4½
Columbia: Mount Pleasant	250	....	4
Crawford:			
Oil Creek	1,700	5	5
Wenango	1,960	6	5–6
Cumberland: Lower Allen	2,350	....	5
Dauphin: Jefferson	583	....	5
Delaware:			
Ashton	12,000	....	4
Darby	3,500	....	5
Edgemont	11,000	....	4½
Middleton	13,000	....	4
Nether Providence	60,000	....	6
Tinnicum	32,000	....	5–6
Upper Chichester	3,400	....	5½
Upper Darby	99,800	20	4½–5
Elk:			
Benzinger	3,450	....	5
Ridgway	29,000	....	6
Franklin: Lurgan	1,000	....	5
Fulton: Brush Creek	5,000	....	5–6
Huntingdon: Springfield	365	....	6
Indiana:			
Conemaugh	8,500	....	5
Pine	447	....	6
White	9,000	....	5
Juniata: Greenwood	200	....	5
Lackawanna:			
Covington	1,500	....	6
Jefferson	1,100	....	6
Lehigh: Whitehall	65,000	20	4
Luzerne:			
Hunlock	2,300	....	6
Plains	45,000	15	5
Plymouth	15,000	....	5
Wilkes-Barre	40,000	....	5
Lycoming:			
Hepburn	3,000	....	5
Lewes	600	....	5
Nippenose	2,380	....	6
McKean:			
Annin	2,200	....	6
Ceres	3,000	....	5
Eldred	1,600	....	5
Foster	6,300	2	6
Hamlin	4,108	....	....
Otto	1,028	....	6
Mifflin: Derry	10,000	....	4
Monroe:			
Jackson	650	....	....
Middle Smithfield	2,000	....	5–6
Paradise	2,000	5	5
Pocono	2,785	....	4–5
Polk[1]	500	....	4
Smithfield	7,000	....	5
Stroud	6,489	....	....
Montgomery:			
Abington	290,000	....	4–4½–5
Cheltenham	155,000	....	3–4
E. Norriton	4,500	....	5
Horsham	25,000	....	4½
Lower Gwynedd	16,000	23	4½
Montgomery	8,000	....	4½
Springfield	20,000	10	4½
Upper Dublin	85,000	3	4½
Upper Providence	9,000	....	4½
W. Norriton	12,500	20	4–4½
Worcester	22,500	....	4–4½
Perry:			
Jackson	840	....	5
Toboyne	200	....	5

[1] Bridge bonds only.

TABLE 23.—*Township highway and bridge bonds*—Continued.

PENNSYLVANIA—Continued.

Connties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Pike:			*Per ct.*
Greene	$3,500	7	5
Lehman	1,700	....	6
Palmyra	1,200	....	5
Potter:			
Bingham	704	....	6
Clara	973	....	6
Eulalia	4,752	....	5
Hector	2,500	....	6
Oswego	1,300	....	5
Pike	8,774	....	5½
Portage	1,500	....	6
Stewardson	2,021	....	6
W. Branch	2,700	....	5
Schuylkill:			
Delano	500	....	5
E. Brunswick	1,600	....	6
N. Manheim	6,323	....	6
Rush	3,000	....	4
Sullivan:			
Colley	492,468	....	....
Forks	800	....	6
Susquehanna:			
Apolacon	1,278	....	6
Auburn	400	....	4
Brooklyn	6,000	....	....
Forest Lake	1,500	....	5
Jackson	213	....	5
Tioga:			
Brookfield	3,769	4	5
Tioga—Continued.			*Per ct.*
Deerfield	$5,100	5	5
Morris	3,357	7	6
Nelson	4,410	....	5–6
Shippen	3,332	....	5
Tioga	3,014	....	6
Union: Hartley	1,275	....	3–4
Venango: Allegheny	1,200	....	....
Warren:			
Conewango	6,600	....	6
Corydon[1]	1,000	....	5
South West	20,000	....	6
Spring Creek	600	....	6
Washington:			
Hanover	3,636	....	....
Independence	20,000	....	6
Wayne:			
Cherry Ridge	500	....	6
Dreher	4,000	....	4
Lehigh	1,600	....	5
Westmoreland:			
Ligonier	8,000	....	5
N. Huntingdon	1,500	....	6
Wyoming: Northumberland	1,200	....	6
Windham	550	....	5
York: Fawn	6,000	....	5
Total	2,333,609	....	....

RHODE ISLAND.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
Washington: South Kingston	$265,000	....	....
Total	265,000	....	....

SOUTH DAKOTA.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
Stanley: Ashcreek	$3,500	5	6
Total	3,500	....	....

VERMONT.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
Addison: Middlebury	$1,500	....	....
Bennington: Bennington Center	10,000	1–13	5
Franklin:			
Berkshire	771	....	....
Sheldon	1,050	....	....

[1] Bridge bonds only.

TABLE 23.—*Township highway and bridge bonds*—Continued.

VERMONT—Continued.

Counties and towns.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
Grand Isle:			*Per cent.*
Grand Isle	$1,000		
Isle La Motte	2,000		
North Hero	1,000		
Total	17,321		

WISCONSIN.

Counties and townships.	Total amount voted to Jan. 1, 1914.	Term of years.	Interest rate.
			Per cent.
La Crosse: Onalaska	$11,000	10	5
Sauk: Delton	16,000		
Total	27,000		

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913.*

ALABAMA.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Blount				$150,000		
Crenshaw				125,000		
Dallas	$100,000	30	5			
Hale	100,000					
Lawrence	123,000	30	6			
Marion				100,000	20	5
Marshall				130,000	30	5
Perry	110,000	30	5			
Russell	100,000	30	5			
Total	533,000			505,000		

ARKANSAS.

Benton				$2,815	12	
Montgomery				10,000		
Woodruff: District 1				30,000	20	6
Total				42,815		

CALIFORNIA.

Kern				$2,500,000	25	5
Orange	$1,370,000		5			
Plumas	100,000	10-25	4			
Riverside				1,500,000		
San Mateo				1,250,000	40	5
Santa Barbara: Carpinteria	50,000	20	6			
Total	1,520,000			5,250,000		

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

DELAWARE.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Kent				$30,000	20	5
New Castle	$105,000		4	[1] 475,000	20–51	4½
Sussex				30,000	5–24	4½
Total	105,000			535,000		

FLORIDA.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Bradford: Hampton				$25,000	20	6
Dade	$250,000					
De Soto				250,000		
Franklin	20,000	20	4½			
Hernando				100,000	30	5
Hillsborough				1,000,000	30	5
Holmes: 1 district				40,000	30	6
Lake				500,000	[2] 15–30	6
Orange	200,000			600,000	30	5½
Palm Beach	200,000					
Pasco				150,000	30	5
Pinellas	370,000	30	5			
Polk: Winterhaven	130,000					
Walton	70,000					
Total	1,240,000			2,665,000		

GEORGIA.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Bleckley				$8,000	30	5
Colquitt				400,000		
Total				408,000		

IDAHO.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Ada				$200,000	10–20	5
Bear Lake	$45,000	20	5½			
Boise	70,000					
Canyon	47,620	10	5			
Fremont: District 1				120,000	10–20	6
Gooding				160,000		
Lincoln:						
Shoshone	80,000	10–20	6			
Richfield				50,000	10–20	6
Twin Falls				[3] 100,000	10–20	5½
Total	242,620			630,000		

[1] Bridges, $250,000. [2] Serial. [3] Bridges, $50,000.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

ILLINOIS.

Counties and districts.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Carroll	Woodland [1]				$1,200		5
	Wysox				3,500	1–5	5
Crawford	Honey Creek	$25,000			35,000	20–25	5
	Lamott	20,000			35,000	20–25	5
	Oblong				35,000	20–25	5
	Robinson	25,000					
Dekalb	Malta	8,500	2	5			
Douglas	Boudre	35,000	13				
	Sargent	35,000	2–7	5			
Edgar	Elbridge	2,500		6			
	Embarrass	35,000	10	5			
Edwards: District 3					3,000	2	6
Fulton	Orion	7,000		5			
Gallatin	Bowlesville	1,000	1–2	4			
	Shawnee	7,000	1–5	4			
Jackson	Carbondale	35,000	3–5	5			
Jefferson	Blissville [1]	500			500		
	Farrington [1]				500		
Kankakee	Ganeer	35,000					
	Momence	35,000					
	Yellowhead	35,000					
La Salle	Farm Ridge				2,000	1	5
Lawrence	Dennison				35,000	3	5
Lee	Ashton	22,000	20	5	22,000	20	5
	China	25,000					
	Harmon				3,000		
	Viola				13,000	1–13	5½
Pike	Derry	3,075		5½			
	Hadley	525					
	Hardin	1,200					
	Kinderhook	700					
	Pleasant Hill	1,200					
St. Clair	Centerville	2,500					
	Fayetteville	2,000					
Sangamon	Salisbury	6,000	5	5			
Stephenson	Jefferson	3,000					
Wayne	Leech [1]				4,000	5	6
	Massilon [1]				3,125	5	6
Whiteside	Sterling	16,000					
Will	Crete				35,000	13	5
	Custer				3,000	3	5
Total		424,700			233,825		

INDIANA.

Counties and districts.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Adams					$151,550	10	4½
	Blue Creek				15,120	(2)	4½
	French				5,280	(2)	4½
	Hartford				8,240	(3)	4½
	Kirkland				10,160	(2)	4½
	Monroe				25,440	(2)	4½
	Preble				6,560	(2)	4½
	Root				17,120	(2)	4½
	St. Marys				6,400	(2)	4½
	Wabash				32,940	(2)	4½
	Washington				69,740	(2)	4½
Allen					53,840	10	4½
	Jackson	$36,320	1–20	4½			
	Lafayette	22,800	1–20	4½			
	Madison	35,930	1–20	4½			
	Maumee	30,842	1–20	4½			
	Monroe	8,240	1–20	4½			
Bartholomew	Townships	82,062			79,216	[3] 10–20	4½
	Clifty	11,520	10	4½			
	Flat Rock	5,000	10	4½			
	Haw Creek	16,500	10	4½			

[1] Bridge bonds only. [2] Six months. [3] Serial.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

INDIANA—Continued.

Counties and districts.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Benton					$111,560		4½
	Grant				11,156	10	4½
	Hickory Grove				2,926	10	4½
	Richland				1,643	10	4½
Boone		$14,040			39,640	10	4½
	Perry	6,000	10	4½			
	Sugar Creek	2,400	10	4½			
	Townships				9,378		
Carroll	Townships	139,000			42,400		
Cass: Districts 1–3					112,425	10	4½
Clark	Bethlehem	9,440	10	5			
	Carr	13,700	10	5			
	Charlestown	43,400	10	5			
	Jeffersonville	38,100	10	5			
	Monroe	29,506	10	5½			
	Union	14,316	10	5			
	Washington	17,948	10	5			
	Wood	9,010	10	5			
Clay					73,800	10	4½
	Perry	9,000		4½			
Crawford	Ohio	6,824		4½			
Daviess					90,000	10	4½
	Madison				56,738	10–20	4½
	Reeve				21,000	1–20	4½
Dearborn		66,063			40,000	1–20	4½
	Center				40,000	20	4½
	Harrison	11,320	1–20	4½			
	Miller				50,000	10–20	4½
Decatur					[1] 63,880	10–15	4½
Delaware					100,000	10–20	4½
Fayette					24,000	10	4½
Fountain		122,750			15,200	10	4½
Gibson					77,300	10	4½
	Center				5,600	10	4½
	Montgomery				26,400	10	4½
	Patoka				18,000	10	4½
	Union				27,300	10	5½
Grant	Townships	550,000	10	4½			
Greene					42,499	10	4½
Hamilton	White River	6,320					
Hancock					[2] 35,500	1–10	4½–6
Harrison					43,220	20	4½
	Harrison	7,100		4½			
	Taylor	9,200					
Henry		10,200		4½			
	Franklin	9,200		4½			
Howard	Union				215,000	10	4½
Huntington		52,988	10	4½	39,653	10	4½
	Jackson				22,425	10	4½
Jackson					[3] 29,640	10	4½
Jasper	Hanging Grove	5,800	10	4½			
	Keener	18,000	10	4½			
	Townships				68,910	10	4–6½
Jay					50,370	10	4½
Jefferson	Township				3,000	20	4½
Jennings					14,300	10	4½
Johnson	Townships				93,400	10	4½
Knox	Vincennes				189,360	10	4½
Kosciusko		1,440	10	4½			
Laporte					208,000	20	4½
Madison		99,380	10	4½			
3 districts					76,120	[4] 10	4½
	Fall Creek				6,240	20	4½
Marion					[5] 228,000	10–20	4½
Marshall					57,000	15	4½
	Bourbon	28,500	15	4½			
Martin		30,000			4,300		4½
	Baker	5,092	12				
Miami		32,550	10–20	4½	70,880	10–20	4½–5
Monroe		96,319					
Morgan		21,000	10	4½	48,200	10	4½
Ohio					9,000	10	5

[1] Bridge bonds, $30,000.
[2] Bridges, $25,000.
[3] Bridge, $15,000.
[4] Serial.
[5] Bridge, $200,000.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

INDIANA—Continued.

Counties and districts.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Owen					$24,159	20	4½
	Marion	$8,972	40	4½			
Parke	Adams				22,658	10	
Perry	Troy	73,000	20	4½			
Pike	Townships				21,000	20	6½
Putnam: Districts 1–3					58,689	10	4½
Rush					259,000	10–20	4½
	Walker	39,800		4½			
St. Joseph		60,000	16	4	24,000	10	4½
Scott	Jennings	8,000	10	4½			
Shelby [1]					80,000	20	4½
	Shelbyville	51,940		4½	28,920	20	4½
Spencer	Ohio	14,320					
Starke					41,000	10	4½
Sullivan					80,982	10	4½
	Jackson	17,960		4½			
Switzerland		22,931	10	4½			
Tippecanoe [1]					260,000	10	4½
Tipton: Districts 1–3					44,080	10	4½
Vanderburg					92,600	10	4½
Vigo					33,800	(2)	4½
Wabash					145,320	10	4½
	Liberty				10,960	10	4½
	Noble				67,540	10	4½
	Pawpaw				12,660	10	4½
Wayne	Green	12,000					
	4 townships				58,660	10	4½
	Wayne	127,500			146,000	10	4½
Wells		105,640					
White		57,600			93,000	10	4½
Total		2,384,783			4,701,997		

IOWA.

Counties.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
			Per cent.			*Per cent.*
Boone	$25,450	12	4½			
Dallas				[3] $67,000		
Fremont [1]				[4] 100,000	20	5
Jackson [1]				[5] 108,000	20	5
Madison				28,000	[2] 3–17	5
Wright [1]				45,000	7–15	5
Total	25,450			348,000		

[1] Bridge bonds only.
[2] Serial.
[3] General funding bonds including gravel roads.
[4] By order of Board of Supervisors.
[5] To fund outstanding bridge warrants.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

KANSAS.

Counties.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Geary		$86,150	10	6			
	Junction City	89,600	9-10	5-6			
Kiowa	Glick	5,000	([1])	5			
Marion					$6,000	5-11	6
Sedgwick					1,550	10	5
Wilson	Center	7,000					
	Guilford	10,000					
Wyandotte		189,000	([2])	4½			
Total		386,750			7,550		

KENTUCKY.

Counties.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
			Per cent.			*Per cent.*
Lewis				$800		
Robertson	$8,000	5-8	5			
Total	8,000			800		

LOUISIANA.

Parishes [3] and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate
			Per cent.			*Per cent.*
Assumption				$80,000	9	5
Bossier				175,000	1-40	5
Calcasieu				900,000	25	5
East Baton Rouge: District 1				37,000	10-20	5
Iberville: Districts 1, 5, and 6	$13,009	1-10	10			
Jefferson	200,000		5			
Lafayette				75,000	25	5
Tangipahoa: District 2				75,000	30	5
Washington				39,477	2-4	5½
Total	213,009			1,381,477		

MAINE.

Counties.	Towns.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Kennebec	Benton				$1,500	5	4
Knox	Vinal Haven				2,500		
Oxford	Norway [4]				35,000	35	4
Penobscot	Orono [5]				12,000	2-4	4
Piscataquis	Foxcroft	$25,000	1-25	4			
Waldo	Frankfort [5]				1,000		5
Washington	Jonesport				1,000	([6])	6
Total		25,000			53,000		

[1] Serial to run until 1918.
[2] Serial to run from 1932 to 1941.
[3] Parishes are equivalent to counties.
[4] For roads and sewers.
[5] Bridge bonds.
[6] Six months.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

MARYLAND.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Caroline				[1] $35,000	20	5
Montgomery: 5 districts	$47,000			25,000	25	4½
Queen Annes	50,000					
Talbot				30,000		
Worcester				25,000	25	5
Total	97,000			115,000		

MASSACHUSETTS.

Counties.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Barnstable [2]					$14,000		
Berkshire					5,000	1–2	4
Bristol	North Attleboro	$6,000	1–6	4	7,000	1–3	4½
Essex					120,000		
Hampden	Russell	5,000		4			
Middlesex	Billerica	9,000					
Nantucket					20,000	5	4
	Nantucket	20,000	10	5			
Norfolk [2]					50,000	([3])	4.92
	Millis	2,400	3	4			
Plymouth [2]					20,000		4
Total		42,400			236,000		

MICHIGAN.

Antrim	Banks				$20,000	[4] 20	5
	Central Lake				20,000		
Baraga	Arven	$10,000					
Benzie	Crystal Lake				20,000		
Berrien					500,000	15	4
	3 townships				89,000		
Delta		100,000	([4])	4½			
Emmet					225,000		
Genesee		500,000	20	4½	200,000	[4] 10	4½
Gogebic		150,000	10	4½			
Grand Traverse	Paradise	30,000					
	Whitewater				24,000		
Huron	Sebewaing	75,000					
	Windsor	50,000					
Ingham					63,652		
Kalkaska	Clearwater	6,000					
	Coldspring	5,000					
	Springfield	9,000					
Kent					265,000	20	4½
Lake	Ellsworth	6,000	5				
Leelanau	Leelanau	20,000					
	3 townships				26,000		

[1] Bridge built from part of this amount.
[2] Bridge bonds only.
[3] Nine months.
[4] Serial.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

MICHIGAN—Continued.

Counties.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Mackinac					$100,000	10–20	5
	Hudson	$4,000					
	Newton	5,000					
Macomb	Lake	50,000					
	Warren	36,000					
Mason	Free Soil	10,000					
Midland					56,000	15	5
Montcalm	Eureka	500	10	5			
Newago	Groton				20,000		
Oceana	Golden	3,000		5			
Ontonagon					38,000	[1] 10	5
Osceola	Lincoln				5,000		
Ottawa		600,000	20	4½			
Tuscola	Fairgrove				20,000		
	Wellington				4,500		
Van Buren	Covert				25,000		
	South Haven	25,000	5	5			
Wexford	Henderson	2,000					
Total		1,696,500			1,721,152		

MINNESOTA.

Counties.	Townships.	1912 Amount voted.	Term of years.	Interest rate.	1913 Amount voted.	Term of years.	Interest rate.
Beltrami					$81,000	20	4
Carlton	Blackhoof	$3,000	15	4			
	Corona	1,500	15	4			
	Mahtowa	3,000	20	4			
	Red Clover	2,000	13	4			
	Split Rock	3,000	13	4			
Kittson	Thompson	7,000		4			
Koochiching	Bannock	3,000	10	4			
	Meding	7,000	10	4			
	Reedy	6,000	10	4			
McLeod	Collins	3,000	6–15	4			
Marshall	Alma	1,200	5–9	4			
	Big Woods	800	5	8			
Millelacs	Page	5,000	9	4			
Ramsey	White Bear	7,500		4			
Winona					50,000	5–7	5
Total		53,000			131,000		

MISSISSIPPI.

Counties and beats.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Adams: Beat 1	$150,000					
Attala	50,000	25	5			
Calhoun	40,000	25	6			
Beat 1	60,000	25	6			
Chickasaw: Beat 3	50,000	20	5	$150,000	20	5
Claiborne				10,000	20	5
Clay:						
Beats 1–3	141,000					
Beat 2				20,000	10–25	6
Coahoma	50,000	30	5			
Copiah	159,000					
Beat 2				75,000	25	6
Covington	50,000					
De Soto: Beats 1, 2, 3, and 5	250,000					
Forrest	100,000	10–25	5			
Beats 1 and 3				100,000	40	5

[1] Serial.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

MISSISSIPPI—Continued.

Counties and beats.[1]	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
George	$30,000	30	6			
Greene				$10,000	1–10	6
Grenada	45,000	20	5			
Hancock	100,000	20	6	50,000	20	6
Hinds: Beats 1 and 5				200,000	25	5
Issaquena				20,000	40	6
Itawamba				65,000		
Jackson	65,000					
Jasper	25,000	25	5			
Jones: Beat 2				50,000	25	5
Lafayette	180,000	25	5½–6			
Lamar	51,000			20,000		
Lauderdale: Beat 5	50,000	30	5	100,000	30	5
Lee:						
Beats 1 and 3	50,000	25	5½			
Beats 1 and 2				80,000	25	5½–6
Leflore				100,000	20	5
Lowndes: Beat 2				50,000	10–20	5
Monroe: Beats 1, 4, and 5	50,000	25	5			
Montgomery: Beat 1	40,000	10–20	5			
Neshoba				100,000		
Noxubee				380,000		
Beats 1, 2, 3, and 5	377,500	25	5½			
Panola				50,000		6
Pike				200,000		
Pontotoc				5,000	20	
Prentiss: Beat 1	50,000	20	6	40,000	25	6
Quitman				25,000		
Rankin: Beat 2				10,000		
Scott: Beat 1	75,000	20	6			
Simpson: Beats 1 and 2				40,000	20	5½
Tallahatchie	25,000	25	6			
Beats 1–5				75,000	25	6
Warren	65,400	20	5	300,000		
Yalobusha:						
Beats 1 and 4	25,000	25	5½			
Beats 2 and 4				48,000	25	5½–6
Yazoo: 4 beats				77,500	25	6
Total	2,403,900			2,450,500		

MISSOURI.

Counties and districts.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Boone: Harg		$20,000	10	6			
Cedar		19,000	2–15	5½			
Clay: 2 districts		135,000					
Dade: 1 district		30,000					
Greene		12,000			$78,000		
Grundy					5,000		6
Howell		30,000					
Laclede		50,000					
Lawrence: Mount Vernon		50,000	15	5			
Mississippi: 1 district		7,000					
New Madrid: King's Highway and Malden Risca		20,000					
Newton: Neosho					30,000	15	6
Nodaway		15,000	(2)	6			
	Polk[3]				50,000		
Stone: 1 district		10,000	17	6			
Total		398,000			163,000		

[1] Counties subdivided into beats and districts. [2] Serial. [3] Bridge bonds only.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

MONTANA.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Blaine	$40,000	20	5			
Cascade	60,000					
29 districts [1]				$45,000	20	5
Custer	170,000	20	4½			
Lincoln	125,000	20	5			
Musselshell	80,000	20	5			
Sanders: 20 districts				15,000	[2] 5–20	5
Teton	100,000	5–20	5			
33 districts				[3] 100,000	20	5
Total	575,000			160,000		

NEBRASKA.

Lincoln				$15,000		
Scotts Bluff: Precincts	$10,000	20	5			
Total	10,000			15,000		

NEW JERSEY.

Counties.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Atlantic		$30,000					
	Egg Harbor	30,000	8–13	4½			
Bergen		11,000	30	4½			
Camden		57,000	5	4½			
Cape May		53,500	30	4½	$70,000	30	4½
Cumberland		9,000	9	4½			
Essex		100,500	40	4			
Gloucester		130,000	1–13	4½			
Hudson		320,666		4–4½			
Hunterdon		45,000	25	4	84,000	30	4
Mercer		40,500	20–30	4	14,500	30	4½
Middlesex		48,000		4½	143,500		
Ocean					35,000	30	5
Passaic					[4] 136,000	14–18	5
Sussex		17,600					
Warren					30,000	5–10	4
Total		892,766			513,000		

NEW MEXICO.

County.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Dona Ana				$100,000	32	5

[1] Bridge bonds only. [2] Serial. [3] Bridges, $30,000. [4] Bridge, $26,000.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

NEW YORK.

Counties.	Towns.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Cayuga					$29,777	1–20	4½–5
Chautauqua	French Creek	$3,000	3	4½			
	Kiantone	4,000	4				
Chemung	Big Flats	7,000		4½			
	Chemung	20,000		4½			
	Elmira	3,408		4½			
Essex	Chesterfield	1,500					
	Keene	3,000					
Fulton	Caroga	35,000	6	5			
Greene		45,500					
Herkimer	Fairfield				5,000		
	Frankfort	2,765	4	5½			
	German Flats	6,000					
	Herkimer [1]	20,732	11	4⅓	67,500		4.6
	Manheim	19,771	12	4½			
	Newport	8,000	16	4			
	Russia	3,000					
	Salisbury	5,900	5	5			
	Schuyler	12,530					
	Webb	17,000	19	5			
Lewis		12,362	25	5			
	Lowville	9,000					
Livingston					12,750	4	4¾
Nassau		240,000	5–20	4½	500,000	6–20	4½–4.7
Niagara					4,000		
Oneida	Kirkland	5,400					
Orleans		21,750	6	5			
Otsego	Maryland	3,000					
	Westford	2,500					
Putnam					38,000	15	4¾
Rensselaer		150,000			81,000		
St. Lawrence		125,000	4–9	4			
Schenectady	Princetown [1]				1,200		
Seneca					20,335	10	4.7
Steuben	Corning	4,000	2–5	5			
Suffolk					55,000	13½	4½
Tompkins		23,000	(1)	4½			
	Lansing	5,000	(1)	4½			
	Trumansburg	10,000					
Warren		50,000	11	5			
Westchester		89,560			[2] 30,000	20–25	
	Eastchester	46,500		4–5			
	New Castle	141,500					
	White Plains	30,000					
Total		1,186,678			844,562		

NORTH CAROLINA.

Counties and districts.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Anson		$50,000			$50,000		
Beaufort					[3] 50,000		
Brunswick					40,000		
Buncombe					50,000		5–6
Burke	Morganton				50,000		
Cabarrus		105,000					
Caldwell	Lovelady				25,000		
Carteret	Morehead				10,000	42	5
	Newport				3,000	42	5
Catawba	Hickory	50,000					
	Newton	50,000					

[1] Serial.
[2] Bridge bonds only.
[3] By act of legislature county commissioners have authority to sell bridge bonds without vote of people.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

NORTH CAROLINA—Continued.

Counties and districts.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Cherokee		$187,000					
Cleveland					$60,000	40	
	Townships	25,000	15	5	50,000		
Davie					175,000		
Duplin	Calypso	5,000					
	Faison	15,000					
	Rosehill	20,000					
	Wallace	5,000					
	Warsaw	20,000					
Edgecombe: Districts 1, 2, 3, 4, 5, 8, 9, 10, and 11					200,000	55	
Franklin	Franklinton	20,000	20	5–5½	20,000		
	Youngsville	15,000					
Granville		40,000					
Greene	Voted by all townships, except 3.				180,000		
Halifax	Enfield				60,000		
	Halifax				40,000		
Haywood	Waynesville	50,000		5			
Henderson		24,000			25,000		
	Edneyville				12,000		
	Hendersonville				50,000		
	Hoopers Creek				20,000		
Iredell		400,000					
Jackson	Cullowhee				30,000		
	Dillsboro				15,000		
	Sylva				30,000		
Lee		100,000	40	5			
Lincoln					200,000	40	
McDowell	Marion				50,000		6
	Nebo				10,000		6
	Old Fort				20,000		6
Macon	Franklin				100,000		
Madison					300,000		
	Township	10,000					
Martin	Robersonville				50,000		
Moore	Deep River				12,500		
	Greenwood				10,000		
	Mineral Springs				10,000		
Nash	Rocky Mount	20,000					
	Mannings				50,000		
New Hanover					[1] 350,000	25	
Onslow	Jacksonville				10,000		
Orange		250,000					
Pitt	Greenville				50,000	40	5
Polk					[2] 100,000	30	
Richmond	Beaver Dam	10,000					
	Black Jack	5,000					
	Marks Creek	15,000					
	Mineral Springs	5,000					
	Rockingham	25,000					
	Steeles	15,000					
	Wolf Pitt	25,000					
Rutherford					250,000	40	
Sampson		10,000			100,000	20	
Scotland	Stewartsville	50,000					
	Williamson	30,000					
	Laurel Hill	30,000	30	4			
	Spring Hill	20,000		4			
Stokes	Danbury				15,000	30	6
	Meadows				40,000	30	6
	Sauratown				50,000	30	6
Surry	Mount Airy	5,000	30	5	80,000		
Vance					200,000	20–40	
Warren	Warrenton				50,000		
Wayne	Brogden				40,000		
	Goldsboro				100,000		
Yancey					150,000		
Total		1,706,000			3,642,500		

[1] Including $250,000 for bridges.

[2] By act of legislature.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

OHIO.

Counties and districts.	Townships.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Ashland					$194,000	10	5
	Sullivan				25,000	10–18	5
	Troy				70,000	10–18	5
Ashtabula					[1] 75,000		
Auglaize					[2] 78,000	13–26	5
Belmont	Washington	$40,000		5			
	York	14,000	16	5			
Coshocton					[3] 100,000	10	5
Cuyahoga		2,003,220	1–30		1,000,000	1–31	5
	Euclid	4,000	24	4½			
Defiance[4]					65,000	4–65	5
Erie	Groton	25,000		4½			
Fayette[4]					9,000	([5])	5
Fulton					30,000	5	5
Gallia					14,000	2–8	5
Hancock		120,500					
Henry					28,750	5	5
Highland: 2 districts					7,850	5	5
Huron	Norwalk	20,000					
	Ridgefield	20,000		5			
	Sherman	25,000	10	5			
Lake					62,000	20	4½
Lawrence					30,000	4½–5	
Licking		210,000			[6] 374,000	5–25	5–5½
Lorain: District 1					180,000	13	5
	Four townships	175,000					
Lucas		139,535					
Madison[4]					80,000	10	5
Mahoning	Springfield	40,000					
District 1					150,000	25	5
Mercer					54,600		5–5½
Miami					60,000		
Montgomery					330,000		5
Muskingum					[7] 875,000		5
Noble	Caldwell				6,000	15–21	6
	Noble	10,000		4–5			
Ottawa	Catawba	20,000					
	Danbury	8,400		5			
Paulding		24,000			134,300	7	5
Perry					45,000	10	5
Pike					14,000	2–13	5
Portage	Brumfield	6,900					
Putnam		155,000	5–10	5			
Ross					[8] 86,000	25–30	
Sandusky					[9] 37,650	5	5
Scioto					[10] 440,000		5
Stark					[11] 545,000	5–15	5
Summit[4]		40,000			23,000		
Trumbull					[12] 245,000		5
Districts 1 and 2		60,000					
	Vienna	25,000		5			
Tuscarawas: 68 districts					130,000	1–3	6
Union					53,600		
Van Wert					16,600	12–21	5
	Tully	15,900	23	4–5			
Warren[4]					262,000	1–30	4–5
Washington[4]					190,000	1–22	5–5½
Wayne[4]					20,000		
Williams[4]					5,000		5
Wood					[13] 156,000	5	5
Wyandot	Tymochtee	20,000	4½–5				
Districts					7,200	10	5
Total		3,221,455			6,308,550		

[1] Flood bonds.
[2] Bridge $70,000.
[3] Emergency road and bridge bonds.
[4] Bridge bonds only.
[5] Nine months.
[6] Bridge $24,000.
[7] Of this amount $775,000 for bridges.
[8] Bridge and refunding bonds.
[9] Bridge $25,000.
[10] Flood and emergency bonds, by authority of H. B. 640.
[11] Bridge $190,000.
[12] Bridge $85,000.
[13] Bridge $6,000.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

OKLAHOMA.

Counties.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Carter	Berwyn				$15,000	15	6
Creek	Sapulpa				50,000	20	5
Rogers	Catoosa				3,000	25	6
	Verdigris				14,288	25	6
Stephens	King	$27,500	15	6			
Wagoner		75,000					
Total		102,500			82,288		

OREGON.

Counties.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
			Per cent.			*Per cent.*
Clatsop				$400,000	20	5
Jackson				500,000	10–30	5
Multnomah [1]				1,250,000	1–30	5
Total				2,150,000		

PENNSYLVANIA.

Counties and districts.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Allegheny					$1,550,000	30	4½
Berks		$475,000	2–12	3½			
Cameron	Lumber	600	3	5–6			
	Shippen	3,000	10	6			
Carbon: Districts (55)					50,000	5	4
Lackawanna					200,000	15	4½
Luzerne					[2] 260,000	30	4½
McKean	Ceres	1,000		5			
	Hamlin	4,108					
Potter					25,000		5
Sullivan	Forks	800		6			
Washington					220,000	1–20	4¾
Westmoreland					250,000	20	4½
York					35,000		
Total		484,508			2,590,000		

RHODE ISLAND.

County.	Town.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Washington	South Kingston	$100,000					

[1] Bridge bonds only. [2] Bridge $100,000.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

SOUTH CAROLINA.

Counties.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Laurens	$50,000		4½			
Marion	40,000		4½			
Richland	75,000		5½			
Total	165,000					

SOUTH DAKOTA.

Counties.	Township.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Pennington[1]		$44,000	1–10	5			
Stanley		13,500					
	Ashcreek	3,500	5	5			
Total		61,000					

TENNESSEE.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Benton				$200,000		
Bradley				25,000	25–30	5
Campbell[1]				4,000	1	
Carter	$12,944					
Dickson				250,000	30	5
Greene: 25 districts				500,000	30	5
Hamblen	25,000	40	5			
Hickman[1]				17,500	12½	5½
Jackson				100,000	30	5
Jefferson				150,000	30	
Loudon	100,000			150,000	30	5
Montgomery				120,000	30	5
Perry				14,500	7	5
Polk				330,000	30	5–6
Roane				110,000	30	5
Sevier: 17 districts				185,000		
Shelby				600,000	12	5
Sullivan	200,000	20–30	4½	30,000		
Sumner	200,000	30	4½			
Wayne	1,200					
White	90,000					
Total	629,144			2,786,000		

[1] Bridge bonds only.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

TEXAS.

Counties[1] and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Anderson	$150,000	20	5			
Atascosa				$20,000		
Austin: Districts 1–3	200,000	5–40	5			
Bastrop: Districts 1–2	100,000	20–40	5	80,000		
Baylor	100,000					
Bee	15,000	20	5			
Bell	7,960			3,980		
District 1				200,000	40	5½
Bexar				750,000	40	5
Bosque: District 7	40,000	40				
Brazoria: District 3	150,000	34	5½			
Brooks	45,000	40	5			
Calhoun				5,000	40	5
Districts 1 and 2	100,000	40	5	135,000		
Cameron				20,000		
Cass: District 7				35,000	40	5
Chambers	14,000					
District 1	6,000	20	5			
District 4				100,000		
Collin				450,000		
Comal				[2] 75,000	40	5
Cooke	1,190					
Crockett				40,000	40	5
Culberson				50,000	40	5
Dallas	5,000					
Denton: District 1	75,000	40	5			
Ellis	173,000					
El Paso	17,000			350,000		
Fort Bend	30,000			175,000		
Frio	1,990			80,000	40	5
Galveston				250,000	40	5
Garza				50,000	40	4
Gonzales: District 1	150,000		5			
Grayson				35,000		
Districts 1 and 2	400,000	40	5			
Gregg				50,000		
Grimes	125,000					
Guadalupe				1,600		
Harris: Districts 5 and 6	212,000	(3)	5			
Hill: Precinct 1				250,000	40	5
Houston: Districts 1 and 3	174,000					
Howard	100,000					
Irion				20,000	40	5½
Jim Wells				125,000	10	5
Johnson				75,000		
Jones				3,000	20	5
Kerr	20,000	5–40	5	40,000		
Kinney				80,000		
Lamar: Precinct 1				100,000	10–40	5
Leon:						
Districts 1–6	84,000					
District 7				50,000		
Liberty	225,000			200,000		
Limestone				150,000		
District 4	150,000	10–40	5			
Matagorda: Districts 1, 2, and 4				460,000		
McLennan: District 1	100,000	40	5			
Medina: District 4				40,000	40	5
Midland				50,000		
Milam: Districts 2 and 5				200,000	40	
Montgomery: District 1				100,000	40	5
Navarro: Districts 1 and 3				475,000	40	5
Nolan	15,000					
Nueces				165,000		
Orange	200,000					
Polk				40,000	4	5
Refugio	25,000			25,000		
Robertson	500,000	40	5			
Districts 1, 2, and 5				250,000		
San Saba				1,990		
Smith				376,250	40	5
Somervell: District 1	16,900					

[1] Counties subdivided into districts and precincts.
[2] Issued by commissioner's court.
[3] Serial.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

TEXAS—Continued.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Sterling				$10,000		
Tarrant	$1,600,000					
Tom Green [1]				70,000	10–40	5
Trinity: District 1				120,000	40	5
Walker				150,000		
Waller: Waller				15,000	40	5
Wharton: District 1	300,000	(2)	5			
Wood	120,000					
Zavalla				[3] 1,999	40	5
Total	5,748,040			6,598,819		

UTAH.

Counties.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Boxelder	$175,000	20	4½			
Grand [1]	8,500	20	5			
San Juan				$14,500	20	
Total	183,500			14,500		

VERMONT.

Counties.	Towns.	1912			1913		
		Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
				Per ct.			*Per ct.*
Addison	Middlebury				$1,500		
Bennington	Bennington Center				10,000	13	5
Franklin	Berkshire				771		
	Sheldon				1,050		
Total					13,321		

VIRGINIA.

Counties and districts.	1912			1913		
	Amount voted.	Term of years.	Interest rate.	Amount voted.	Term of years.	Interest rate.
			Per cent.			*Per cent.*
Accomac:						
Atlantic	$50,000		5			
Lee				$50,000		5½
Augusta: South River	250,000	30	5			
Brunswick	81,000		5			
Culpeper: Catalpa	120,000	(2)	5			

[1] Bridge bonds only.
[2] Serial.
[3] Issued by commissioner's court as emergency bonds.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

VIRGINIA—Continued.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
			Per ct.			*Per ct.*
Dickenson: Clintwood and Kenady	$54,000	2–30	5	$32,000		
Fairfax: Mount Vernon				90,000		
King George				10,000		
Lee				76,000		5
Lunenburg: 3 districts	40,000		6	64,000		5½
Nelson				35,000	32	5
Northampton:						
Eastville	50,000					
Franktown	20,000	30	4¾			
Orange	125,000	10–20	5			
Pittsylvania: Dan River	100,000	34	5			
Pulaski: Dublin	100,000	10–30	5			
Rappahannock				64,000		5
Rockingham: Plains	30,000	10	6			
Russell				150,000		5
Scott:						
Estillville				100,000	20–30	5
Fulkerson				33,800	20–30	5
Johnson				33,300	20–30	5
Smyth: Marion and St. Clair				225,000		5
Spotsylvania: Berkeley and Livingstone				100,000	30	5
Stafford	100,000					
Warren				60,000		5
Westmoreland				25,000		5
Wise				260,000	30	5
Total	1,123,000			1,408,100		

WASHINGTON.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Asotin				$35,000		
Clallam	$300,000	20	5			
Clarke [1]				500,000		
King	3,000,000	20	5			
Okanogan: District 1	15,000	10	10			
Snohomish: Delta				75,000		
Total	3,315,000			610,000		

WEST VIRGINIA.

Counties and districts.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
Hancock:						
Butler	$125,000	34	5			
Baxter and Grant	125,000	10–34	5			
Logan [1]				$60,000	20	5
Marion:						
Fairmont				400,000	30	5
Mannington				300,000	30	5
Marshall	150,000	34	5			
Pleasants: St. Marys				60,000	30	5
Wetzel: Grant				150,000	34	6
Wood: Parkersburg	180,000	30	4½			
Total	580,000			970,000		

[1] Bridge bonds only.

TABLE 24.—*County, district, and township highway and bridge bonds voted during 1912 and 1913*—Continued.

WISCONSIN.

Counties.	Townships.	1912 Amount voted.	1912 Term of years.	1912 Interest rate.	1913 Amount voted.	1913 Term of years.	1913 Interest rate.
				Per ct.			*Per ct.*
Ashland		$25,000	20		$25,000	20	4
Columbia		20,000	20				
Iron		35,000	6	4			
La Crosse	Onalaska				11,000	10	5
Sauk [1]					24,000	20	4½
Vilas		60,000	20	5			
Total		140,000			60,000		

[1] Bridge bonds only.

TABLE 25.—*Counties, districts, beats, and townships giving complete mileage returns of roads built from proceeds of bonds.*

State.	Counties, districts, beats, and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned. Sand-clay.	Gravel.	Macadam.	Bituminous macadam.	Total.	Remarks.
Alabama	Autauga	$65,000	100				100	
	Bullock	160,000	95	5			100	
	Dallas	410,000	44	137			197	Includes 16 miles graded.
	Elmore	170,000	55	56			111	
	Jackson	250,000		32	76		108	
	Marshall	130,000	35	30	10		75	
	Mobile	500,000					42	About 1 mile of bituminous concrete pavement; 5 miles of chert gravel and 36 additional miles in course of construction.
	Morgan	240,000	4	1	60		65	
	Pike	192,000	230				230	
	Russell	100,000	63.5	1.5			65	
	St. Clair	85,000		85			85	
Arizona	Yuma	500,000		150	50		200	
Arkansas	Woodruff: District 1.	30,000		6			29	23 miles of graded road.
California	Glenn	450,000		160			160	
	Kern	2,500,000		38.1	183.4		339.5	118 miles graded.
	Los Angeles	3,500,000				248	248	
	Orange	1,370,000				107	107	
	Sacramento	600,000				104	104	
	San Diego	1,250,000					450	Mostly surfaced with disintegrated granite; 44 miles concrete.
	San Mateo	1,298,000		20	48		112	44 miles not specified.
Delaware	New Castle	1,285,000	60	2.9	161.66	2.06	226.62	Of this amount $275,000 was used for bridges.
Florida	Columbia	40,000	86				86	
	Hillsborough	1,400,000					70	Brick.
	Manatee	250,000			64		64	
	Nassau	60,000					22	Shell.
	Orange	800,000					80	65 miles of brick; rest not specified.
	Pasco	150,000			30		30	
	St. Lucie	200,000					50	Rock 25 miles, marl 15 miles, and shell 10 miles.

TABLE 25.—*Counties, districts, beats, and townships giving complete mileage returns of roads built from proceeds of bonds*—Continued.

State.	Counties, districts, beats, and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned.					Remarks.
			Sand-clay.	Gravel.	Macadam.	Bituminous macadam.	Total.	
Georgia	Ben Hill	$75,000	125				125	
Idaho	Fremont: District 1.	120,000		60			60	
Indiana	Adams	151,550			36.9		36.9	
	Allen	53,840			10.34		10.34	
	Boone	223,260		104.5			105	$\frac{1}{2}$ mile of brick road.
	Cass: Districts 1-3.	112,425		12	15	8	35	
	Daviess	90,000		27	3		30	
	Delaware	100,000		20	10		30	
	Gibson	77,300			20		20	
	Hancock	273,500		76.5	.5		77	Bridge bonds, $25,000.
	Henry	44,269		21.5		5	26.5	
	Jay	50,370		6.5	9		15.5	
	Martin	189,881		84.54			84.54	
	Miami	636,656		204.38	9.65		214.03	
	Morgan	341,200		273	75		348.75	$\frac{3}{4}$ mile of brick road.
	Union	60,000		14	6		20	
	Vanderburg	266,196			60		60	
Kansas	Johnson	61,269			13		13	
Kentucky	Lewis	6,200		5			5	
	Ohio	30,000			10		10	
Louisiana	Assumption	86,000		46			46	
	De Soto	60,000	71				71	
	East Baton Rouge.	22,000		15			15	
	Iberville: Districts 1, 5, and 6.	14,329		10.5			10.5	
Maryland	Cecil	100,000			3	14	17	
	Prince Georges	16,000		10			10	
Michigan	Alpena	100,000		40			40	
	Baraga	40,000	20	10			30	
	Berrien	500,000			100		100	
	Genesee	700,000		141	14		155	
	Mackinac	100,000		35			35	
	Mason	100,000		32	3		35	
	Midland	56,000		10	5		15	
	Ontonagon	38,000		6	6		12	
	Wayne	2,000,000					83.5	Includes 80 miles of concrete; rest not specified.
	Wexford	50,000		6	4		10	
Minnesota	Lake	20,000	20				20	
	St. Louis	300,000		175			175	
Mississippi	Jackson	160,000	75				125	25 miles of clay and 25 miles of shell.
	Jasper	25,000	40				40	
	Lauderdale	350,000	32.25		51.75		84	
	Neshoba	100,000			28		28	
	Prentiss: Beat 1.	40,000		25			25	
	Yalobusha	62,000	150				150	
	Beats 2 and 4	48,000	110				110	
Missouri	Callaway	100,000		16	12		28	
	Lafayette	125,000			14		14	
	Lawrence: Mount Vernon	50,000			12		12	
	Pettis	200,000		15	45		60	
Montana	Lewis and Clark	105,000		20			20	
	Lincoln	125,000		40			40	
Nevada	Churchill	23,000	15				15	
	Ormsby	40,000	7		7		14	
New Jersey	Atlantic	307,000		6			19	13 miles of concrete road.
	Cumberland	43,000		20.36			20.36	
	Essex	1,140,505			158		158	
	Morris	400,000			85		85	
	Sussex	154,100			26		26	
New Mexico	Dona Ana	100,000		40			40	

TABLE 25.—*Counties, districts, beats, and townships giving complete mileage returns of roads built from proceeds of bonds*—Continued.

State.	Counties, districts, beats, and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned.					Remarks.
			Sand-clay.	Gravel.	Macadam.	Bituminous macadam.	Total.	
New York	Franklin	$500,000					124	Gravel and macadam.
North Carolina.	Alamance	200,000			45		45	
	Cabarrus	145,000		15	12	6	33	Also 10 steel bridges.
	Cumberland	40,000	50				50	
	Edgecombe: Districts 1–5, 8–11.	200,000	450				450	
	Gaston	300,000	10		90		100	
	Guilford	300,000		15	105		120	
	Haywood	60,000	1	2	30		33	
	Lee	100,000	8	84			92	
	Vance	218,000		200			200	
Ohio	Fayette	909,000		421	4		425	Of this amount $9,000 was used for bridges.
	Franklin	513,260			32	30	65	3 miles of brick.
	Geauga	20,000					2	2 miles of brick.
	Hancock	408,000		2	100		102	
	Highland	7,850		1.2	1.2		2.4	
	Hocking	50,000		2.5	3		7	1.5 miles of brick.
	Licking	701,000			95		133.5	5 miles of concrete and 33.5 miles of brick.
	Mahoning: District 1.	150,000			7.1		14.3	Glutrin 2.6 miles and brick 4.6 miles.
	Mercer	2,134,600		454	135		590.83	Concrete 1⅝ miles.
	Montgomery	477,000		15	55	1	71	
	Morgan	40,000			3.5		4.75	Brick, 1.25 miles.
	Noble	48,000					6	Concrete, 6 miles.
	Preble	11,160			2		2	
	Trumbull	755,000		10	116		128	Concrete, 2 miles. Bridge, $85,000.
Oregon	Jackson	500,000				52	52	
Pennsylvania	Allegheny	15,900,000			604.78	[1]134.1	836.36	$550,000 bridge bonds. Concrete .62 mile, brick 74.86 miles, and plank 22 miles.
	Carbon	50,000			10		10	
South Carolina.	Dillon	100,000	70				70	Concrete bridge, $17,500.
Tennessee	Campbell: Districts 1–5.	200,000		32	35		67	
	Dickson	250,000		100			100	
	Hamblen	325,000			100		100	
	Polk	405,000		110	15		125	
Texas	Baylor	100,000	83				83	
	Bell: 2 districts.	200,000		90			90	
	Bexar	1,250,000	11	230			241	
	Bosque: District 7.	40,000		10			10	
	Brown: District 1.	150,000	35	60			95	
	Comal	153,000		50			50	
	Cooke: District 1.	100,000		28			28	
	El Paso	617,000	10	3		55	68	
	Freestone: District 1.	50,000	41				41	
	Gonzales: District 1.	150,000	35	40			75	
	Hall	65,000		15		5	20	
	Hays: District 1.	87,000	6	30	9		45	
	Hill: Precinct 1.	250,000		80			80	
	Jackson	124,500	200				200	
	Jefferson	809,500			100		100	

[1] Includes 68.1 miles of bituminous-gravel road.

TABLE 25.—*Counties, districts, beats, and townships giving complete mileage returns of roads built from proceeds of bonds*—Continued.

State.	Counties, districts, beats, and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned.					Remarks.
			Sand-clay.	Gravel.	Macadam.	Bituminous macadam.	Total.	
Texas	Jim Wells	$125,000		100			100	
	Leon: Districts 1, 2, 4, 5, 6.	84,000	77				77	
	McCulloch	118,000	41.5	27.5			69	
	McLennan	150,000		64			64	
	Mitchell: District 1.	30,000	27				27	
	Smith	405,000	300				300	
	Stonewall	50,000	40				40	
	Taylor: District 1.	150,000		35	5		40	
	Waller	25,000	23	2			25	
	Williamson	300,000		150			150	
Virginia	Amherst	215,000		1.5	30.5		32	
	Culpeper: Catalpa.	120,000			30		30	
	Dickenson:							
	Clintwood	54,000	7		7		14	
	Kenady	32,000		16			16	
	Dinwiddie	105,000		125			125	
	Lee	440,000			36		84	Includes 48 miles of graded road.
	Montgomery	30,000			8		8	
	Nelson	35,000			7		7	
	Norfolk	200,000			30		30	Proceeds of issue to build 3 toll roads and 3 toll bridges.
	Orange	175,000			30		30	
	Rappahannock: Wakefield.	30,000			7.5		7.5	
	Rockingham: Plains.	30,000			5		5	Mileage built with proceeds of bond issue and joint county and State funds.
	Spotsylvania	100,000		41.8			41.8	
	Warren: District 2.	60,000		14	1		15	
	Wise	960,000			48.2		131	Includes 82.8 miles earth graded.
West Virginia	Marion:							
	Fairmont	400,000					22	Concrete and brick.
	Mannington	300,000					19	
Wisconsin	Florence	38,000	13.18	1.84	7.78		22.8	
	Vilas	60,000	30				30	
Total		63,932,720	3,006.43	5,030.62	3,497.76	771.16	[1] 13,825.28	

[1] In this total there are included the following:

	Miles.
Bituminous concrete pavement	1
Concrete (exclusive of West Virginia)	152.45
Chert gravel (36 miles of this in course of construction)	41
Brick (exclusive of West Virginia)	256.96
Rock	25
Shell	57
Disintegrated granite surfaced	406
Clay	25
Marl	15
Glutrin	2.6
Plank	22
Graded road	287.8
Road not specified	62.5
Total (exclusive of West Virginia)	1,354.31

TABLE 26.—*Townships and towns* [1] *giving complete mileage returns of roads built from proceeds of bonds.*

State.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned.				
			Sand-clay.	Gravel.	Macadam.	Bituminous macadam.	Total.
Illinois	Carroll: Wysox	$38,500			15		15
	Lee: Ashton	44,000			12		12
Indiana	Bartholomew:						
	Flat Rock	55,500		18.5			18.5
	Wayne	35,240		17			17
	Clay: Sugar Ridge	545,726		343			343
	Daviess:						
	Reeve	21,000		5			5
	Washington	913,988		295.62			295.62
	Gibson:						
	Center	48,460			13		13
	Johnson	69,600			16		16
	Montgomery	171,620			41		41
	Wabash	21,000		6.5			6.5
	White River	85,830			22		22
	Hamilton:						
	Fallcreek	25,931		20			20
	Washington	65,691		35			35
	White River	86,985		50			50
	Henry: Franklin	14,000		6			6
	Huntington: Jackson	32,425		8	3		11
	Knox: Vincennes	189,360		90			90
	Madison: Fall Creek	6,247		2.5			2.5
	Marshall: Bourbon	28,500			8.5		8.5
	Shelby: Shelby	126,097		33.5			33.5
	Wayne:						
	Franklin and New Garden	7,180		2			2
	Green	12,000			2.5		2.5
Massachusetts	Franklin: Gill	4,500		2.5			2.5
Michigan	Baraga: Covington	18,000		8	2		10
	Berrien: Lincoln	20,000		2.5	3		5.5
	Clare: Redding	3,000		2			2
	Delta:						
	Ford River	3,000			1		1
	Wells	10,000			3.5		3.5
	Gogebic: Marenisco	20,000		8			8
	Lake: Ellworth	6,000		3			3
	Monroe: Bedford	39,000			11		11
	Oceana: Hart	44,250			7.85		7.85
	Osceola: Osceola	25,000	2	3.75			[2] 8
	Schoolcraft: Mueller	6,000	6				6
	Wexford: Henderson	2,000		1			1
Minnesota	Cook:						
	Colvill	12,000	15				15
	Maple Hill	15,000	10	2			12
	Itasca:						
	Balsom	20,000	17				17
	Marcell	10,000	5	3			8
	Trout Lake	8,500	10				10
	Roseau: Spruce	5,000	2	2			4
New Jersey	Burlington: Pemberton	10,000		3			3
	Cape May: Lower	5,000		3			3
New York	Chemung: Big Flats	40,645			8		8
	Fulton: Caroga	35,000		.5	4.5	2	7
	Westchester:						
	Scarsdale	147,350			13	7	20
	White Plains	218,000			17	6	23
Ohio	Ashland: Montgomery	98,000		33			33
	Belmont: York	32,000			5		5
	Crawford: Whetstone	250,000		130			130
	Huron:						
	Norwich	46,000			10.75		10.75
	Sherman	40,000			10.25		10.25
	Lorain: Columbia	24,000			6		6
	Mahoning:						
	Poland	115,000					[3] 12.5
	Smith	100,000					[3] 5
	Springfield	90,000			1		[4] 7.33
	Medina: Medina	127,500	41		14		55
	Ottawa: Catawba	20,000	5	4			9

[1] In New York and the New England States the town is synonymous with township.
[2] Concrete road, 2.25 miles.
[3] Brick roads.
[4] Brick road, 6.33 miles.

TABLE 26.—*Townships and towns giving complete mileage returns of roads built from proceeds of bonds*—Continued.

State.	Counties and townships.	Total amount voted to Jan. 1, 1914.	Miles of road built and planned.				
			Sand-clay.	Gravel.	Mac-adam.	Bituminous macadam.	Total.
Ohio (contd.)	Richland: Weller	$42,000			9		9
	Seneca: Bloom	72,500					[1] 4
	Trumbull: Liberty	100,000					[1] 9
Pennsylvania	Montgomery:						
	Horsham	25,000			6.5		6.5
	Worcester	22,500			5		5
	Warren: South West	20,000	4		2		6
Wisconsin	La Crosse: Onalaska	11,000		10			10
	Sauk: Delton	16,000			4		4
	Total	4,623,625	117	1,153.87	277.35	15	[2] 1,602.30

[1] Brick roads.
[2] In this total there are included 2.25 miles of concrete road and 36.83 miles of brick road; total, 39.08 miles.

TABLE 27.—*Summary of all highway and bridge bonds voted to Jan. 1, 1914.*

State.	State bonds.	County and district bonds.	Township bonds.
Alabama		$5,121,500	
Arizona		808,000	
Arkansas		1,218,315	
California	$18,000,000	15,630,800	
Colorado		134,700	
Connecticut	10,500,000		$576,500
Delaware		1,395,000	
Florida		7,285,000	
Georgia		1,176,000	
Idaho	505,000	1,221,837	
Illinois		420,320	1,618,634
Indiana		18,072,049	35,837,348
Iowa		4,006,314	
Kansas		1,132,375	677,065
Kentucky		1,759,872	
Louisiana		1,932,840	
Maine	2,000,000		78,000
Maryland	9,170,000	750,500	
Massachusetts	14,365,000	813,000	650,473
Michigan		6,382,152	1,926,135
Minnesota		1,388,350	982,805
Mississippi		8,710,872	
Missouri		1,721,500	65,000
Montana		2,239,606	
Nebraska		553,500	246,170
Nevada		175,000	
New Hampshire	1,300,000		40,000
New Jersey		14,386,782	760,600
New Mexico	500,000	246,500	
New York	100,000,000	9,097,923	2,631,165
North Carolina		5,541,273	2,751,300
North Dakota		63,000	
Ohio		35,241,828	5,283,805
Oklahoma		1,440,000	382,288
Oregon		2,150,000	
Pennsylvania		24,839,050	2,333,609
Rhode Island	1,800,000		265,000
South Carolina		410,000	
South Dakota		77,300	3,500
Tennessee		12,674,298	
Texas		24,960,837	
Utah	260,000	440,500	
Vermont			17,321
Virginia		6,632,400	
Washington	190,000	4,408,262	
West Virginia		2,500,000	
Wisconsin		244,000	27,000
Total	158,590,000	229,403,355	57,153,718

APPENDIX C.

TABLE SHOWING COST ELEMENTS OF GRAVEL, MACADAM, AND BITUMINOUS MACADAM ROADS IN MAINE, MASSACHUSETTS, AND NEW JERSEY.

TABLE 28.[1]—*Table showing cost elements of gravel roads for years 1908–1911.*

No.	Location.	Length (feet).	Width (feet).	Total cost of work.	Percentage of cost.		Cost per mile of equivalent 20-foot width.		
					Drainage and grading.	Surfacing.	Drainage and grading.	Surfacing.	Total.
	1908.								
1	Camden, Me.	1,400	26	$1,795.07	69.40	30.62	$3,612	$1,596	$5,208
2	Eastport, Me.	1,900	25	1,634.00	50.00	50.00	1,816	1,816	3,632
3	Lisbon, Me.	1,800	24	1,703.63	52.53	47.40	2,189	1,975	4,164
4	Presque Isle, Me.	1,115	40	1,526.95	46.35	53.50	1,676	1,937	3,614
5	Richmond, Me.	775	36	1,066.91	53.90	46.10	2,165	1,858	4,023
6	Rockland, Me.	1,250	20	2,382.17	70.30	29.80	7,078	2,987	10,065
7	May's Landing, N. J.	73,603	16	37,416.42	34.38	65.62	1,153	2,201	3,355
8	Red Lion, N. J.	19,272	12	12,607.26	36.64	63.36	2,108	3,648	5,756
9	Tuckahoe, N. J.	17,946	14	25,558.10	54.96	45.04	5,945	4,834	10,780
10	Malaga, N. J.	30,307	24	14,040.13	29.46	70.54	600	1,436	2,037
11	Half Acre, N. J.	17,793	20	9,961.89	63.89	36.11	1,887	1,068	2,955
12	Farmingdale, N. J.	15,840	20	9,232.61	34.78	63.06	1,070	1,940	3,010
13	Eatontown (1st), N. J.	17,160	14	32,439.77	14.01	86.12	1,980	12,285	14,265
14	Bayhead, N. J.	24,662	24	25,950.75	36.63	63.34	1,695	2,950	4,645
15	Lakehurst, N. J.	33,448	24	22,955.98	55.57	44.51	1,677	1,343	3,020
16	Aldine, N. J.	7,001	20	11,110.11	56.71	43.28	4,752	3,625	8,377
	1909.								
17	Fairfield, Me.	1,819	15	1,165.35	74.11	25.87	3,353	1,166	4,520
18	Falmouth, Me.	1,541	21	1,021.12	85.51	14.48	2,842	480	3,323
19	Jay, Me.	1,100	15	1,386.71	77.06	22.94	6,833	2,038	8,872
20	Presque Isle, Me.	1,100	40	1,500.45	56.27	44.39	2,039	1,600	3,639
21	Rockland, Me.	1,600	23	2,366.01	62.00	38.39	4,201	2,603	6,805
22	Sanford, Me.	2,425	22	2,773.71	55.22	44.89	3,017	2,454	5,471
23	English Creek, N. J.	35,481	20	15,061.12	38.94	61.05	873	1,368	2,241
24	Chestnut Neck, N. J.	2,745	27.5	5,697.15	85.44	14.58	6,805	1,161	7,967
25	Schellenger's Landing, N. J.	11,066	20	12,258.99	54.37	45.62	3,225	2,670	5,895
26	Goshen, N. J.	13,743	20	10,688.66	35.40	64.69	1,451	2,655	4,106
27	Tuckahoe, N. J.	22,513	20	24,544.00	53.10	46.91	3,055	2,700	5,755
28	Rio Grande, N. J.	15,348	20	14,556.54	34.17	65.83	1,711	3,300	5,011
29	Cranbury, N. J.	12,994	20	5,912.88	40.37	59.63	970	1,432	2,402
30	Allentown, N. J.	19,668	18	13,439.93	36.78	63.21	1,474	2,533	4,007
31	Lakewood, N. J.	11,404	14	8,448.00	36.08	63.92	2,014	3,571	5,586
32	Lakewood, N. J.	15,137	24–36	15,048.63	54.32	45.68	1,900	1,600	3,500
33	Barnsboro, N. J.	17,476	20	12,589.80	41.15	65.99	1,565	2,510	4,075
34	Alloway, N. J.	25,132	20	21,100.29	55.56	44.44	2,462	1,970	4,432
	1910.								
35	Augusta, Me.	3,500	21	2,727.64	13.49	46.78	529	1,833	2,362
36	Bridgton, Me.	2,500	15	1,657.69	71.04	28.96	3,312	1,366	4,678
37	Camden, Me.	1,300	21	1,883.25	21.56	78.48	1,569	5,714	7,283
38	Dexter, Me.	712	21	1,239.67	42.37	57.63	3,714	5,038	8,752
39	Eastport, Me.	2,375	18	1,128.74	56.61	43.38	1,575	1,208	2,784
40	Fairfield, Me.	1,500	22	3,786.74	63.74	36.27	7,545	4,390	11,936
41	Gorham, Me.	1,250	23	967.70	31.50	68.48	1,119	2,434	3,553
42	Kennebunk, Me.	4,996	21	2,435.71	13.31	87.00	427	2,023	2,450
43	Lisbon, Me.	1,800	24	1,053.02	37.65	62.35	970	1,605	2,575
44	Millinocket, Me.	1,500	30	1,071.32	29.97	70.30	756	1,760	2,516
45	Milo, Me.	1,500	21	1,018.30	36.99	63.01	1,214	2,150	3,364
46	Mount Desert, Me.	1,030	22	1,370.47	85.22	14.78	5,456	945	6,401
47	Norway, Me.	1,115	23	1,028.61	90.65	9.40	3,836	398	4,234
48	Orono, Me.	1,800	25	1,043.20	68.21	31.80	1,670	779	2,449
49	Paris, Me.	1,450	25	1,080.00	24.06	75.92	756	2,384	3,140

[1] This table was compiled from the annual reports of the State highway departments of the three States concerned. Geographical names given in New Jersey are sometimes not names of places, but of roads or streets.

TABLE 28.—*Table showing cost elements of gravel roads for years 1908–1911*—Contd.

No.	Location.	Length (feet).	Width (feet).	Total cost of work.	Percentage of cost. Drainage and grading.	Percentage of cost. Surfacing.	Cost per mile of equivalent 20-foot width. Drainage and grading.	Cost per mile of equivalent 20-foot width. Surfacing.	Cost per mile of equivalent 20-foot width. Total.
	1910—Continued.								
50	Presque Isle, Me	1,600	21	$1,675.05	41.92	58.10	$2,205	$3,380	$5,586
51	Rockland, Me	2,000	24	2,193.74	88.16	11.84	4,245	570	4,815
52	Sanford, Me	1,900	26	1,860.29	32.15	67.85	1,280	2,700	3,980
53	Scarboro, Me	2,000	21	1,048.13	19.11	80.89	502	2,133	2,636
54	Waterville, Me	1,800	29	1,803.05	24.70	75.26	901	2,743	3,644
55	Yarmouth, Me	1,360	24	1,738.48	42.49	54.66	2,550	3,075	5,625
56	Cologne, N. J	42,646	20	19,575.36	27.38	72.62	664	1,760	2,424
57	Deans, N. J	14,509	20	9,773.00	34.48	65.52	1,227	2,333	3,560
58	Red Bank, N. J	20,201	18	19,735.21	30.24	69.82	1,735	4,005	5,741
59	Farmingdale, N. J	10,032	18	11,427.88	64.89	35.11	4,332	2,344	6,677
60	Lakewood, N. J	13,200	14	7,381.65	43.91	56.09	1,851	2,364	4,215
61	Barnsboro, N. J	17,476	20	8,489.80	61.02	38.98	1,564	999	2,564
	1911.								
62	Allentown, N. J	10,274	18	15,117.98	35.61	64.39	3,082	5,520	8,602
63	Red Bank, N. J	8,184	18	17,262.78	17.54	80.96	2,592	9,994	12,586
64	Lakewood, N. J	18,458	14	8,737.53	60.55	39.52	2,160	1,410	3,570
65	Lakewood, N. J	5,174	14	3,579.96	50.01	49.99	2,610	2,607	5,217
66	Cedar Ave., N. J	13,807	16,18	22,442.25	21.70	78.30	2,190	7,731	9,921
67	Seaside Park, N. J	28,395	24	42,347.32	35.61	64.38	2,337	4,225	6,562
68	Elmerborough, N. J	9,387	18,42	8,048.75	23.58	76.42	710	2,305	3,016
69	Camden, Me	1,000	30	1,588.77	42.10	57.92	2,353	3,233	5,586
70	Dexter, Me	1,400	26	1,105.20	40.43	59.65	1,293	1,911	3,205
71	Eastport, Me	1,844	22	1,175.15	59.47	40.53	1,818	1,238	3,056
72	Fairfield, Me	650	23	1,549.41	60.91	39.09	6,652	4,282	10,934
73	Farmington, Me	1,350	23	1,225.00	52.37	47.61	2,181	1,982	4,163
74	Freeport, Me	900	20	1,440.16	34.24	65.76	2,892	5,550	8,442
75	Gorham, Me	2,050	23	1,220.39	42.33	57.69	1,156	1,575	2,732
76	Kennebunk, Me	4,135	21	2,221.16	37.98	62.00	1,028	1,675	2,703
77	Lisbon, Me	1,350	21	1,880.97	39.65	55.03	2,771	4,228	7,000
78	Millinocket, Me	1,280	30	1,238.44	32.29	67.72	1,100	2,306	3,407
79	Norway, Me	1,300	23	1,096.23	42.74	57.25	1,655	2,213	3,868
80	Old Orchard, Me	1,200	21	1,019.15	43.57	56.43	1,860	2,417	4,278
81	Orono, Me	2,316	25	1,017.03	57.86	42.17	1,648	800	2,448
82	Presque Isle, Me	1,600	24	1,390.28	41.90	58.10	1,599	2,233	3,832
83	Princeton, Me	1,536	24	1,148.25	88.67	11.32	2,910	371	3,281
84	Rockport, Me	630	21	1,031.82	68.09	31.91	5,600	2,628	8,228
85	Sanford, Me	1,800	24	1,565.99	12.93	87.09	495	3,333	3,829
86	Windham, Me	2,000	25	940.69	63.28	35.82	1,284	712	1,996
87	Yarmouth, Me	1,200	24	1,414.13	49.57	50.42	2,533	2,615	5,148
	Total and weighted averages	[1] 143.53	20	4,417.00	41.15	58.85	1,817	2,599	4,416

[1] Miles.

TABLE 29.[1]—*Table showing cost elements of water-bound macadam roads for years 1908–1911.*

No.	Location.	Length (feet).	Width (feet).	Total cost of work.	Percentage of cost.		Cost per mile of equivalent 15-foot width.		
					Drainage and grading.	Surfacing.	Drainage and grading.	Surfacing.	Total.
	1908.								
1	Augusta, Me	1,800	21	$2,556.29	44.9	55.1	$2,410	$2,950	$5,360
2	Biddeford, Me	1,800	27	4,067.68	48.8	51.2	3,240	3,400	6,640
3	Brewer, Me	1,300	47	2,198.44	26.6	73.4	760	2,080	2,840
4	Calais, Me	2,100	21	1,787.05	26.9	73.1	860	2,340	3,200
5	Caribou, Me	670	45	1,646.14	25.5	74.5	1,100	3,220	4,320
6	Farmington, Me	1,000	16	1,207.99	14.8	85.2	880	5,090	5,970
7	Gardiner, Me	1,660	21	1,978.10	22.4	77.6	1,000	3,490	4,490
8	Houlton, Me	2,000	21	2,033.50	21.6	78.4	830	3,000	3,830
9	Jay, Me	1,000	16	1,140.18	13.8	86.2	780	4,860	5,640
10	Saco, Me	866	35	1,898.45	19.7	80.3	980	3,970	4,950
11	Sanford, Me	2,400	16	2,632.04	75.6	24.4	4,100	1,320	5,420
12	Skowhegan, Me	1,900	15	2,027.85	56.5	43.5	3,180	2,450	5,630
13	South Portland, Me	640	20	1,356.30	20.4	79.6	1,710	6,670	8,380
14	Riverdale, N. J	26,240	14	33,437.76	31.3	68.7	2,260	4,950	7,210
15	Westwood, N. J	6,260	14	8,225.83	20.2	79.8	1,500	5,940	7,440
16	Franklin, N. J	8,400	14	16,199.90	59.7	40.3	6,520	4,400	10,920
17	Summit, N. J	9,770	14	17,352.93	41.2	58.8	4,140	5,900	10,040
18	Lumberton, N. J	2,060	14	31,110.00	5.1	94.9	440	8,110	8,550
19	Westfield, N. J	16,470	14	32,745.23	19.8	80.2	2,230	9,010	11,240
20	West Fairfield, N. J	11,160	16	17,494.24	12.5	87.5	970	6,780	7,750
21	Westville, N. J	7,750	16	11,104.20	25.0	75.0	1,780	5,330	7,110
22	Harrison Street, N. J	6,860	16	10,549.60	30.5	69.5	2,320	5,280	7,600
23	Watchung, N. J	4,650	16	17,074.76	63.3	36.7	11,510	6,670	18,180
24	High Street, N. J	5,240	16	10,817.30	44.3	55.7	4,530	5,690	10,220
25	Whitehouse, N. J	34,190	14	52,982.30	28.0	72.0	2,460	6,310	8,770
26	Etra, N. J	6,280	14	9,329.38	18.6	81.4	1,560	6,840	8,400
27	Brunswick, N. J	19,540	16	34,663.66	22.6	77.4	1,980	6,800	8,780
28	Colonia, N. J	8,400	14	14,444.61	33.4	66.6	3,250	6,470	9,720
29	Cranbury, N. J	5,300	14	7,059.80	14.6	85.4	1,100	6,430	7,530
30	Livingston Avenue, N. J	5,910	16	10,693.87	14.0	86.0	1,250	7,690	8,940
31	Main Street, Woodbridge, N. J.	9,240	14	19,271.27	42.1	57.9	4,970	6,830	11,800
32	State St., Perth Amboy, N. J.	7,180	14	10,995.50	27.9	72.1	2,420	6,250	8,670
33	River Road "A," N. J	8,760	14	17,157.42	33.1	66.9	3,660	7,410	11,070
34	River Road "B," N. J	15,620	14	32,805.66	39.1	60.9	4,630	7,220	11,850
35	Jamesburg, N. J	15,100	14	21,102.39	20.4	79.6	1,840	7,190	9,030
36	Manalapan, N. J	1,400	14	3,616.45	17.5	82.5	2,560	12,060	14,620
37	Rumson Road, N. J	4,010	16	9,123.39	19.4	80.6	2,180	9,070	11,250
38	Eatontown (2d), N. J	17,480	14	25,988.28	21.1	78.9	1,780	6,640	8,420
39	Allentown, N. J	5,040	18	10,664.37	13.1	86.9	1,220	8,090	9,310
40	Midvale, N. J	16,530	16	43,422.05	71.9	28.1	9,350	3,660	13,010
41	Macopin, N. J	9,820	14	20,544.09	66.1	33.9	7,820	4,010	11,830
42	South Bound Brook, N. J	11,880	14	21,113.73	41.2	58.8	4,140	5,910	10,050
43	Dead River, N. J	11,190	14	18,589.99	29.5	70.5	2,770	6,620	9,390
44	North Broad Street, N. J	5,050	16	15,801.63	30.1	69.9	4,670	10,830	15,500
45	Terrill Road, N. J	5,300	16	8,054.08	28.9	71.1	2,170	5,350	7,520
	1909.								
46	Brewer, Me	1,575	24	1,486.75	12.7	87.3	390	2,720	3,110
47	Calais, Me	2,100	21	1,811.65	20.4	79.6	660	2,590	3,250
48	Camden, Me	750	30	1,712.52	50.9	49.1	3,070	2,960	6,030
49	Caribou, Me	533	37	1,106.00	13.6	86.4	610	3,840	4,450
50	Dexter, Me	675	19	1,009.30	55.3	44.7	3,430	2,780	6,210
51	Eden, Me	1,100	24	3,012.18	50.7	49.3	4,580	4,450	9,030
52	Gardiner, Me	1,200	21	3,038.32	26.3	73.7	2,510	7,030	9,540
53	Houlton, Me	1,500	21	2,499.73	50.5	49.5	3,170	3,100	6,270
54	Rumford, Me	6,831	20	7,364.80	32.5	67.5	1,380	2,880	4,260
55	Saco, Me	775	35	2,060.80	14.6	85.4	880	5,150	6,030
56	Skowhegan, Me	1,550	15	2,134.85	48.2	51.8	3,500	3,760	7,260
57	South Portland, Me	525	25	1,420.34	13.7	86.3	1,190	7,370	8,560
58	Waterville, Me	1,300	40	2,726.40	8.5	91.5	350	3,800	4,150
59	Yesler Way, N. J	14,020	14	18,850.72	32.9	67.1	2,500	5,100	7,600
60	Valley Road, N. J	16,530	14	15,409.85	25.4	74.6	1,340	3,940	5,280
61	Bridge Street, N. J	700	16	2,374.79	36.5	63.5	6,140	10,720	16,860
62	Whitehouse, N. J	30,980	14	42,934.46	41.0	59.0	3,210	4,630	7,840
63	North Crosswicks, N. J	1,160	16	2,354.95	11.0	89.0	1,100	8,930	10,030
64	Cheesequakes Creek, N. J	10,400	14	33,366.90	57.0	43.0	10,340	7,810	18,150
65	Jamesburg, N. J	6,970	14	10,782.65	9.9	90.1	860	7,890	8,750

[1] See footnote 1, Table 28, p. 86.

TABLE 29.[1]—*Table showing cost elements of water-bound macadam roads for years 1908–1911*—Continued.

No.	Location.	Length (feet).	Width (feet).	Total cost of work.	Percentage of cost.		Cost per mile of equivalent 15-foot width.		
					Drainage and grading.	Surfacing.	Drainage and grading.	Surfacing.	Total.
	1909—Continued.								
66	Keyport, N. J.	6,340	16	$16,850.21	53.7	46.3	$7,070	$6,100	$13,170
67	Penn's Grove, N. J.	15,950	16	26,599.42	20.5	79.5	1,690	6,560	8,250
68	Terrill (1), N. J.	620	14	1,014.17	21.8	78.2	2,010	7,200	9,210
69	Green Brook, N. J.	6,120	14	12,469.55	43.8	56.2	5,050	6,470	11,520
70	Washington Valley, N. J.	10,940	14	26,714.22	60.4	39.6	8,510	5,570	14,080
71	Frankford, N. J.	18,240	14	34,747.92	47.7	52.3	5,140	5,640	10,780
72	Morris, N. J.	6,180	16	11,210.09	50.1	49.9	4,500	4,480	8,980
73	New Brunswick, N. J.	3,960	16	10,246.74	46.7	53.3	5,980	6,830	12,810
	1910.								
74	Augusta, Me.	585	21	831.12	4.4	95.6	240	5,110	5,350
75	Bath, Me.	1,680	20	2,370.50	31.5	68.5	1,760	3,830	5,590
76	Biddeford, Me.	1,324	21	2,625.50	18.9	81.1	1,410	6,070	7,480
77	Brewer, Me.	1,500	40	1,996.84	39.9	60.1	1,050	1,590	2,640
78	Calais, Me.	1,400	21	1,625.53	39.9	60.1	1,740	2,630	4,370
79	Caribou, Me.	773	27	2,234.00	44.9	55.1	3,810	4,670	8,480
80	Dover, Me.	455	36	1,222.56	23.8	76.2	1,410	4,500	5,910
81	Fort Fairfield, Me.	832	32	1,487.00	49.7	50.3	2,200	2,220	4,420
82	Freeport, Me.	700	21	1,230.74	33.9	66.1	2,250	4,380	6,630
83	Hallowell, Me.	437	39	1,240.90	17.2	82.8	990	4,770	5,760
84	Houlton, Me.	1,400	22	2,252.00	33.4	66.6	1,930	3,850	5,780
85	Jay, Me.	1,150	21	1,235.56	19.0	81.0	770	3,280	4,050
86	Oldtown, Me.	1,005	21	1,821.93	32.6	67.4	2,230	4,600	6,830
87	Rumford, Me.	4,320	23	6,227.56	25.6	74.4	1,270	3,690	4,960
88	Berwick, Me.	800	21	1,016.94	27.0	73.0	1,300	3,500	4,800
	1911.								
89	Brunswick, Me.	1,300	21	1,836.82	25.7	74.3	1,370	3,950	5,320
90	Caribou, Me.	333	46	1,406.24	30.4	69.6	2,210	5,060	7,270
91	Hallowell, Me.	500	20	1,080.00	19.2	80.8	1,640	6,910	8,550
92	Houlton, Me.	1,700	21	2,667.10	21.5	78.5	1,270	4,640	5,910
93	Oldtown, Me.	800	22	1,829.07	42.9	57.1	3,530	4,700	8,230
94	Rumford, Me.	1,125	23	2,604.47	18.5	81.5	1,480	6,500	7,980
95	Wilton, Me.	1,200	21	1,311.21	28.7	71.3	1,180	2,920	4,100
	1910.								
96	Ringoes, N. J.	21,550	14	36,425.67	31.6	68.4	3,020	6,540	9,560
97	Asbury, N. J.	5,280	14	7,500.00	34.4	65.6	2,770	5,270	8,040
98	Main Street, N. J.	68,800	14	15,810.67	43.2	56.8	5,620	7,380	13,000
99	Frankford, N. J.	18,250	14	34,747.92	47.7	52.3	5,140	5,630	10,770
	1911.								
100	Smalley's Corner, N. J.	16,860	15	22,759.49	24.1	75.9	1,890	5,960	7,850
101	Brunswick, N. J.	5,340	16	10,450.65	15.4	84.6	1,490	8,200	9,690
102	Yardville, N. J.	18,000	14	32,396.84	15.5	84.5	160	860	1,020
103	Greater Cross Roads, N. J.	10,470	14	20,633.71	29.6	70.4	3,300	7,850	11,150
104	Buttzville, N. J.	19,420	14	31,371.99	37.6	62.4	3,430	5,700	9,130
	Total and weighted averages.	[2] 137.51	15	8,688.00	36.89	63.11	3,400	5,815	9,215

[1] See footnote 1, Table 28, p. 86.

[2] Miles.

TABLE 30.[1]—*Table showing cost elements of bituminous-macadam roads for 1908–1911*

No.	Location.	Length (feet).	Width (feet).	Total cost of work.	Percentage of cost.		Cost per mile of equivalent 15-foot width.		
					Drainage and grading.	Surfacing.	Drainage and grading.	Surfacing.	Total.
	1908.								
1	Kennebunk, Me.	426	27	$1,597.30	25.3	74.7	$2,780	$8,220	$11,000
2	Waterville, Me.[2]	760	46	3,565.18	11.5	88.5	930	7,150	8,080
	1909.								
3	Camden, N. J.	12,693	14	29,043.42	28.3	71.7	3,660	9,290	12,950
4	Evesham, N. J.[3]	12,838	14	22,649.61	20.8	79.2	2,080	7,910	9,990
5	Hopewell, N. J.[2]	10,720	18	16,121.40	21.0	79.0	1,390	5,230	6,620
6	Trenton, N. J.	13,227	16	24,509.44	20.3	79.7	1,870	7,320	9,190
7	Helmetta, N. J.	14,271	14	21,375.59	11.3	88.7	960	7,510	8,470
8	Plainsboro, N. J.	12,992	14	21,596.57	13.7	86.3	1,290	8,100	9,390
9	Terrill, N. J.	9,982	16	26,404.08	37.2	62.8	4,870	8,230	13,100
10	Stoutsburg, N. J.	10,845	14	19,741.90	22.0	78.0	2,270	8,030	10,300
11	Edgar, N. J.	17,526	16	42,424.74	25.0	75.0	2,990	8,990	11,980
12	Washington Avenue, N. J.	6,125	16	14,230.20	23.4	76.6	2,690	8,810	11,500
13	Walnut Avenue, N. J.	6,313	16	15,868.00	19.7	80.3	2,450	9,990	12,440
	1910.								
14	Belfast, Me.[4]	580	21	1,997.53	43.7	56.3	5,670	7,310	12,980
15	Coffin's Corner, N. J.	11,866	14	25,138.87	14.8	85.2	1,780	10,220	12,000
16	Nicholson, N. J.	6,532	14	13,168.82	14.6	85.4	1,660	9,740	11,400
17	Brown's Corner, N. J.	8,601	14	20,468.00	24.3	75.7	3,270	10,180	13,450
18	Runnymeade, N. J.	8,984	16	19,408.76	30.9	69.1	3,310	7,390	10,700
19	Mountain, N. J.	325	16	561.00	5.0	95.0	430	8,190	8,620
20	River Road, N. J.	6,458	16	13,705.67	13.7	86.3	1,440	9,070	10,510
21	Kingston, N. J.	3,805	14	6,555.88	17.9	82.1	1,740	8,000	9,740
22	Somerset Street, N. J.	2,040	14	4,252.27	45.5	54.5	5,380	6,440	11,820
23	Seventh Street, N. J.	8,700	14	15,213.40	14.4	85.6	1,390	8,290	9,680
24	Morris Plains, N. J.	13,718	14	33,176.53	26.9	73.1	3,680	9,990	13,670
25	Gladstone, N. J.	21,053	14	42,979.47	27.3	72.7	3,130	8,320	11,450
26	Pompton, N. J.	15,516	14	18,930.85	29.2	70.8	2,020	4,890	6,910
27	Union, N. J.	4,164	14	12,251.98	8.1	91.9	1,350	15,290	16,640
28	Warrenville, N. J.	3,600	14	8,310.13	48.8	51.2	6,370	6,690	13,060
29	Frankford, N. J.	17,309	14	25,313.87	37.6	62.4	3,110	5,170	8,280
30	Raritan, N. J.	13,013	16	40,820.75	28.1	71.9	4,360	11,170	15,530
31	Washington Avenue, N. J.	1,300	16	3,272.00	29.4	70.6	3,670	8,810	12,480
32	Beattystown, N. J.	45,341	14	73,580.20	40.1	59.9	3,680	5,500	9,180
	1911.								
33	Brunswick, Me.	640	21	1,461.37	11.2	88.8	970	7,660	8,630
34	East Livermore, Me.	750	26	1,621.35	14.1	85.9	930	5,650	6,580
35	Saco, Me.	580	28	1,925.00	34.4	65.6	3,230	6,160	9,390
36	Chapel, N. J.	4,515	14	12,681.75	28.1	71.9	4,470	11,450	15,920
37	Railroad, N. J.	859	30	4,587.51	9.6	90.4	1,350	12,720	14,070
38	Swedesboro, N. J.	18,115	16	45,633.30	10.4	89.6	1,300	11,170	12,470
39	Rocky Hill, N. J.	4,200	14	8,744.39	35.4	64.6	4,170	7,600	11,770
40	Springfield, N. J.	8,362	16	26,965.52	23.4	76.6	3,730	12,230	15,960
41	Agawam, Mass.[2]	4,720	15	9,726.00	29.3	70.7	3,188	7,692	10,880
42	Chester, Mass.[2]	8,000	15	14,996.00	42.9	57.1	4,246	5,652	9,898
43	Franklin, Mass.[5]	6,360	15	5,547.00	39.4	60.6	1,814	2,791	4,605
44	Holliston, Mass.[5]	9,800	15	10,796.00	46.2	53.8	2,687	3,130	5,817
45	Ipswich, Mass.[5]	4,860	15	5,683.00	34.2	65.8	2,112	4,062	6,174
46	Lakeville, Mass.[2]	10,250	15	14,492.00	39.0	61.0	2,911	4,554	7,465
47	Lanesborough, Mass.[2]	9,070	15	13,080.00	46.7	53.3	3,556	4,059	7,615
48	Milford, Mass.[2]	6,210	15	11,804.00	50.7	49.3	5,089	4,948	10,037
49	Plainville, Mass.	2,570	15	5,053.00	37.5	62.5	3,893	6,489	10,382
50	Seekonk, Mass.[2]	7,920	15	5,552.00	16.6	83.4	615	3,088	3,703
51	Tyngsborough, Mass	4,250	15	8,301.00	30.5	69.5	3,145	7,167	10,312
52	Wilmington, Mass.	5,790	15	10,570.00	20.2	79.8	1,947	7,692	9,639
53	do	7,450	15	11,517.00	24.9	75.1	2,032	6,130	8,162
	Total and weighted averages	[6] 84.63	15	10,267.00	26.85	73.15	2,765	7,533	10,298

[1] See footnote 1, Table 28, p. 86.
[2] Bituminous surface coat.
[3] Bituminous pavement on 2,022 square yards.
[4] Bituminous-macadam surface 62 per cent.
[5] Five inches of gravel and a bituminous surface coat.
[6] Miles.

APPENDIX D.

THEORY OF INTEREST APPLIED TO HIGHWAY-BOND CALCULATIONS, WITH SINKING FUND, ANNUITY, AND INTEREST TABLES FOR 60 INTERVALS AND 14 RATES OF INTEREST.

TABLE OF CONTENTS.

APPENDIX D.

THEORY OF INTEREST APPLIED TO BOND CALCULATIONS.

Introduction.—This appendix presents briefly the application of the theory of compound interest to highway bonds. There are six important quantities in terms of which the solution of most problems can be expressed. If i is the rate of interest and n the term of years, these quantities are:

The accumulation of 1 at the end of n years, r^n;

The accumulation of an annuity of 1 per annum at the end of n years, $s_{\overline{n}|}$;

The annual sinking fund which will accumulate to 1 at the end of n years, $1/s_{\overline{n}|}$;

The present value of 1 due in n years, v^n;

The present value of an annuity of 1 per annum for n years, $a_{\overline{n}|}$; and

The annuity for n years which 1 will purchase, or the annuity necessary to discharge a debt of 1 in n years with interest, $1/a_{\overline{n}|}$.

The first three are accumulative functions and the last three are discount or present value functions.

The mathematical formulas for these six quantities are:

$$r^n = (1+i)^n \qquad s_{\overline{n}|} = \frac{(1+i)^n - 1}{i} \qquad \frac{1}{s_{\overline{n}|}} = \frac{i}{(1+i)^n - 1}$$

$$v^n = (1+i)^{-n} \qquad a_{\overline{n}|} = \frac{1-(1+i)^{-n}}{i} \qquad \frac{1}{a_{\overline{n}|}} = \frac{i}{1-(1+i)^{-n}}$$

The values of most of these functions are given more or less completely in published tables of interest.[1]

Definitions.—*Interest* may be defined as the consideration for the use of capital. The capital is called the *principal.*

The *rate* at which a given principal is earning interest requires the adoption of some interval as the unit of time, and this is usually the *year.*

It is clear that interest when received may be added to the principal and so in turn earn interest. This process, called *compounding,* takes place at the end of *stated intervals,* as every three months, six months, or year.

[1] At the end of this appendix, pages 116 to 127, are short tables to seven places for 60 intervals and 14 interest rates.

Mathematical rates.—The *effective rate of interest* is the interest earned by one unit of principal (one dollar) in one unit of time (one year) when interest *is compounded* at the end of each *stated interval.*

The *nominal rate of interest* is the total interest earned by one unit of principal (one dollar) in one unit of time (one year) when interest *is not compounded* at the end of each *stated interval.*

It follows that the nominal and effective rates of interest coincide only when the *stated interval* is the unit of time (one year).

Commercial rate.—In commercial transactions the rate of interest is usually quoted as a rate *per cent,* or per hundred units of principal, instead of a rate *per unit* of principal, as in the above definitions. To find the mathematical rate as above defined, divide the commercial rate by 100. For example, the mathematical rate corresponding to the commercial rate 6 per cent is 6/100, or .06. The mathematical rate is used in the following formulas.

Relation between effective and nominal rates of interest.—In any transaction there is an effective rate of interest i and a corresponding nominal rate of interest j. This relation can be expressed by an algebraic formula which involves the number of *stated intervals,* m, in one year. At the nominal rate j, during each stated interval $1/m$th of a year in length, one unit of principal would earn j/m in interest which, added to the unit, gives an amount $1+j/m$. If the principal 1 accumulates in the first interval to $1+j/m$, it follows by proportion that the principal $1+j/m$ would accumulate in the second interval to $(1+j/m)^2$. In like manner, at the end of the mth interval, the accumulation would be $(1+j/m)^m$. The total interest earned in the m intervals, or one year, is the difference between the accumulation and the original unit of principal, which by definition is the *effective rate* of interest i. Hence the fundamental formula:

$$\boldsymbol{i=(1+j/m)^m-1} \tag{1}$$

or

$$\boldsymbol{1+i=(1+j/m)^m.} \tag{2}$$

Solving for j, there results

$$\boldsymbol{j=m[(1+i)^{1/m}-1].} \tag{3}$$

The number of times, m, that interest is added, or converted into principal each year, is the *frequency of conversion.* A nominal rate of interest, convertible m times a year, is indicated by the symbol $j_{(m)}$.

Example 1.—The nominal rate of interest j on deposits is 3% and interest is added to the principal every six months; to find the effective rate i.

Here $j=.03$ and $m=2$. From formula (1) there results

$$i=(1+.03/2)^2-1=(1.015)^2-1=.030225.$$

The effective rate 3.0225% is thus slightly higher than the corresponding nominal rate convertible twice per annum.

Example 2.—The effective rate of interest is 6%; to find the corresponding nominal rate when interest is convertible semiannually.

Here i and m are given to find j; hence from formula (3) there results

$$j=2[(1+.06)^{\frac{1}{2}}-1]=2(1.06)^{\frac{1}{2}}-2=2.059126-2=.059126.$$

It is necessary to extract the square root of 1.06. The final result shows that $j=$ 5.9126%, and again the nominal rate is smaller than the corresponding effective rate.

Amount of* 1 *in n years at compound interest.—Let the effective rate of interest be i. At the end of the first year the accumulation is $1+i$. During the second year this principal $1+i$ will be increased in the ratio of 1 to $1+i$, and will therefore amount at the end of the second year to $(1+i)(1+i)$, or $(1+i)^2$. In this way at the end of n years the amount is $(1+i)^n$.

Let P be the principal and S the amount of P at the end of n years at compound interest at the effective rate i. Since 1 amounts to $(1+i)^n$ in n years, P would amount to $P(1+i)^n$. There results, therefore, the formula

$$\boldsymbol{S=P(1+i)^n}. \tag{4}$$

Hence

$$\boldsymbol{P=S/(1+i)^n=Sv^n}, \tag{5}$$

where

$$\boldsymbol{v=1/(1+i)}. \tag{6}$$

If in the above formulas $1+i$ is replaced by $(1+j/m)^m$, to which it is equivalent according to formula (2), it follows that

$$\boldsymbol{S=P(1+j/m)^{mn}}, \tag{7}$$

and

$$\boldsymbol{P=S/(1+j/m)^{mn}=Sv^{mn}}, \tag{8}$$

where

$$\boldsymbol{v=1/(1+j/m)}. \tag{9}$$

These formulas express the relation between P and S in terms of the nominal rate j and the frequency of conversion m. The values to seven places of decimals of $(1+i)^n$ and v^n for various rates of interest and for 60 intervals or years are given in Tables 31 and 34.

Example 3.—To find the amount of \$12,375 at 3% compound interest in 30 years. By formula (4)

$$S=(1+.03)^{30}\times\$12,375=2.4272625\times\$12,375=\$30,037.37.$$

The value of $(1.03)^{30}$ was taken from Table 31.

Example 4.—\$12,375 is placed in a bank; to find the amount in 30 years if interest is 3% and is compounded semiannually.

The nominal rate of 3%, convertible twice a year, requires formula (7) with $j=.03$ and $m=2$. Substituting, the result is:

$$S=(1+.03/2)^{2\times30}\times\$12,375=(1.015)^{60}\times\$12,375=2.4432198\times\$12,375=\$30,234.85.$$

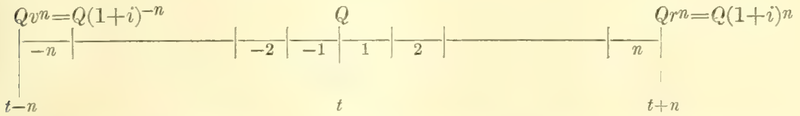
The discount factor.—Because of the power of money to earn interest the value of money depends upon the time to which it is referred. Then in order to compare sums of money due at different times, they must be referred to the *same point in time.*

Formula (5) gives the principal P which will accumulate at the effective rate i in n years to the amount S. If $S=1$ and $n=1$, the formula gives the present value of 1 due in one year. This is usually denoted by the symbol v, so that

$$v=1/(1+i)=(1+i)^{-1}.$$

Similarly $v^2=1/(1+i)^2=(1+i)^{-2}$ is the present value of 1 due in two years, and $v^n=1/(1+i)^n=(1+i)^{-n}$ is the present value of 1 due in n years.

The symbol v is often called the discount factor, and if it is desired to find the value of money *n years before the point in time under consideration,* it is necessary only to multiply the quantity by v^n. The factor $1+i$, which is frequently denoted by r, is accumulative in character, and formula (4) shows that, to find the value of a quantity of money Q, *n years after the point in time under consideration*, it is necessary merely to multiply the quantity by $(1+i)^n$.



More generally, *when i is the effective rate per interval,* the value of Q, at a time n intervals after the point t, is $Q(1+i)^n=Qr^n$, and its value n intervals before point t is $Q(1+i)^{-n}=Qv^n$.

Annuities-certain.—An *annuity* is a series of payments made at *equal intervals* during the continuance of a given *status.*

The *status,* or condition of payment of the annuity, may take a variety of forms. If the status is a fixed term of years, the annuity is an *annuity-certain.* Thus payments of one hundred dollars a year for ten years constitute an annuity-certain. The sum of the payments on an annuity in one year, when the payments are of the same amount, is the *annual rent.*

Payments of twenty-five dollars are made at the end of every month for ten years. This is an annuity-certain with an annual rent of three hundred dollars.

When payments are made at the *end* of each interval, the annuity-certain is said to be *immediate;* when payments are made at the *beginning* of each interval, the annuity-certain is said to be *due.*

Amount of an immediate annuity-certain.—The value of an annuity at the end of its term is called the *amount.* The amount of an immediate annuity-certain for n years with an annual rent 1, payable at the end of each year, is designated by the symbol $s_{\overline{n}|}$. To find $s_{\overline{n}|}$ each annual payment must be accumulated, at the effective rate of interest i, to the end of the term of the annuity. The first payment of 1 accumulates in $n-1$ years to $(1+i)^{n-1}$; the second payment of 1, in $n-2$ years, to $(1+i)^{n-2}$; etc. . . . . ; the $(n-1)$th payment of 1, in 1 year, to $(1+i)$; and the nth payment at the end of the term is 1. Adding the separate amounts in reverse order, there results

$$s_{\overline{n}|} = 1 + (1+i) + (1+i)^2 + \ldots\ldots + (1+i)^{n-1}.$$

The sum of this geometric series is

$$s_{\overline{n}|} = \frac{(1+i)^n - 1}{i}. \tag{10}$$

Values of this quantity are given for various rates of interest and terms in Table 32.

Example 5.—To find the accumulation in 47 years of an annual sinking fund of 1% of \$1,000,000, if the fund is credited annually with 3% compound interest.

This is an application of formula (10) where $n=47$ and $i=.03$; since $s_{\overline{47}|}=100.3965009$ the accumulation will be

$$100.3965009 \times \$10{,}000 = \$1{,}003{,}965.01.$$

The same principles may be applied to find the amount of an annuity for n years with annual rent 1 payable in p equal installments during each year. The amount of such an annuity is designated by the symbol $s^{(p)}_{\overline{n}|}$, and its value is represented by the following formula:

$$s^{(p)}_{\overline{n}|} = \frac{(1+i)^n - 1}{p[(1+i)^{1/p} - 1]}. \tag{11}$$

If $1+i$ is replaced by $(1+j/m)^m$ in accordance with formula (2), the amount of the annuity is then expressed in terms of the nominal rate of interest j with frequency of conversion m, thus:

$$s_{\overline{n}|} = \frac{(1+j/m)^{mn} - 1}{(1+j/m)^m - 1}, \tag{12}$$

$$s^{(p)}_{\overline{n}|} = \frac{(1+j/m)^{mn} - 1}{p[(1+j/m)^{m/p} - 1]}. \tag{13}$$

Example 6.—What will be the accumulation in 47 years of an annual sinking fund of 1% of \$1,000,000, paid in semiannually, if the fund is credited as received with 3% interest compounded annually?

This is an application of formula (11) where $n=47$, $p=2$, $i=.03$, hence

$$s^{(2)}_{\overline{47}|} = \frac{(1+.03)^{47} - 1}{2\,[(1+.03)^{\frac{1}{2}} - 1]} = \frac{3.0118950}{.0297783} = 101.143954$$

and the accumulation will be $101.143954 \times \$10{,}000 = \$1{,}011{,}439.54$.

The special case where interest is converted with the same frequency as the payment of annuity installments, or when $m=p$, deserves particular mention. Formula (13) then reduces to

$$s_{\overline{n}|}^{(p)}=\frac{1}{p}\cdot\frac{(1+j/p)^{np}-1}{j/p}=\frac{1}{p}\cdot s_{\overline{np}|}, \tag{14}$$

where $s_{\overline{np}|}$ is to be taken at the effective rate j/p.

Example 7.—What will be the accumulation in 47 years of an annual sinking fund of 1% of \$1,000,000, paid in semiannually, if the fund is credited with a nominal rate of 3% convertible twice a year?

This is an application of formula (14) where $n=47$, $p=2$, and $s_{\overline{94}|}$ is taken at $1\frac{1}{2}\%$; hence

$$\tfrac{1}{2}s_{\overline{94}|}\times\$10{,}000=\$1{,}017{,}764.25.^{1}$$

Sinking fund which will amount to 1.—An annuity with annual rent of 1 will amount in n years to $s_{\overline{n}|}$; it follows that an annuity with annual rent of $1/s_{\overline{n}|}$ will amount in n years to 1. The quantity $1/s_{\overline{n}|}$ is the *sinking fund* which will accumulate to 1 in n years.

Values for this important function

$$\frac{1}{s_{\overline{n}|}}=\frac{i}{(1+i)^{n}-1} \tag{15}$$

are given for various rates of interest and for terms ranging from 1 to 60 intervals or years in Table 33.

Example 8.—To find an annual sinking fund, which, credited with 3% compound interest, will accumulate in 50 years to \$1,000,000.

Applying formula (15) where $n=50$, and $i=.03$, there results $1/s_{\overline{50}|}=.0088655$. Therefore the required sinking fund is

$$.0088655\times\$1{,}000{,}000=\$8{,}865.50.$$

In like manner $1/s_{\overline{n}|}^{(p)}$ is the annual rent of an annuity which, at the nominal rate j convertible m times a year, will accumulate to 1 in n years. The annual rent is payable in p installments during each year; hence each installment is equal to $1/ps_{\overline{n}|}^{(p)}$. The installments may be regarded as the sinking fund, payable at the end of every pth part of a year, which in n years will accumulate to 1. The amount of each payment to the sinking fund is

$$\frac{1}{ps_{\overline{n}|}^{(p)}}=\frac{(1+j/m)^{m/p}-1}{(1+j/m)^{mn}-1}. \tag{16}$$

When $p=1$ and $m=2$, formula (16) gives the value of the *annual* sinking fund which, improved at compound interest *semiannually*, will accumulate in n years to 1.

The formula simplifies to the following:

$$\frac{(1+j/2)^{2}-1}{j/2}\cdot\frac{j/2}{(1+j/2)^{2n}-1}=s_{\overline{2}|}\cdot\frac{1}{s_{\overline{2n}|}}\quad\text{at } j/2\%. \tag{17}$$

This formula is of considerable practical importance because payments to the sinking fund are usually made annually and the fund

[1] For calculation of $s_{\overline{94}|}$ see Example 22, page 113.

credited with interest semiannually. Table 6, on page 15, was calculated by formula (17).

Example 9.—To find the annual payment which will accumulate in 20 years to \$100.000 when interest is $3\frac{1}{2}$ per cent compounded semiannually.

Taking $n=20$ and $j=.035$ and consulting Tables 32 and 33 with $1\frac{3}{4}$ per cent interest for values of $s_{\overline{2}|}$ and $1/s_{\overline{40}|}$, respectively, there results:

$$s_{\overline{2}|}\cdot\frac{1}{s_{\overline{40}|}}=2.0175\times.0174721=.0352500.$$

Hence the annual payment to sinking fund is

$$.0352500\times\$100,000=\$3,525.00.$$

Example 10.—To find the sinking fund, which set aside semiannually and accumulated as received, with 3% compound interest, will amount in 50 years to \$1,000,000.

Here formula (16) is used with $p=2$, $m=1$, $j=.03$, $n=50$, and

$$\frac{1}{2s^{(2)}_{\overline{50}|}}=\frac{(1+.03)^{\frac{1}{2}}-1}{(1+.03)^{50}-1}=.00439999.$$

The required sinking fund is therefore

$$.00439999\times\$1,000,000=\$4,399.99.$$

In the special case when the frequency of conversion coincides with the number of payments per annum, or $m=p$, the amount of *each payment* to the sinking fund is

$$\frac{1}{ps^{(p)}_{\overline{n}|}}=\frac{j/p}{(1+j/p)^{np}-1}=\frac{1}{s_{\overline{np}|}},\tag{18}$$

where $s_{\overline{np}|}$ is to be taken at rate j/p.

Example 11.—To find a sinking fund which, set aside semiannually and credited with a nominal rate of 3% convertible twice a year, will accumulate in 30 years to \$1,000,000.

Here apply formula (18) by substituting $p=2$, $j=.03$, and $n=30$; this gives

$$\frac{1}{2s^{(2)}_{\overline{30}|}}=\frac{1}{s_{\overline{60}|}}=.0103934,$$

where $1/s_{\overline{60}|}$ is taken at $1\frac{1}{2}$%. Then the sinking fund which would accumulate to \$1,000,000 is

$$.0103934\times\$1,000,000=\$10,393.40.$$

Four important cases of sinking funds are illustrated in the preceding examples. They arise from the fact that payments to a sinking fund may be annual or semiannual and interest on a sinking fund annual or semiannual. Formula (16) covers all of them when p and m are properly chosen. The following schedule illustrates this fact:

Case.	p	Sinking-fund payments.	m	Interest on sinking fund.	Illustrated in example.
1	1	Annual	1	Annual	8
2	1	Annual	2	Semiannual	9
3	2	Semiannual	1	Annual	10
4	2	Semiannual	2	Semiannual	11

In most cases in the illustrative tables in the body of this bulletin, for simplicity of presentation, annual payments and annual interest are assumed, whereas in practice usually annual payments and semi-annual interest are employed.

Present value of an immediate annuity-certain.—The present value of an immediate annuity-certain for n years, with annual rent 1 payable at the end of each year, is designated by the symbol $a_{\overline{n}|}$. It is equal to the sum of the present values of 1, due at the succeeding yearly intervals. By formula (5) the present value of 1, due at the end of one year at the effective rate of interest i, is $v=1/(1+i)$; at the end of two years, $v^2=1/(1+i)^2$, etc. . . . .; at the end of n years, $v^n=1/(1+i)^n$. Hence

$$a_{\overline{n}|}=v+v^2+\dots\dots\dots+v^n$$

$$=\frac{1}{1+i}+\frac{1}{(1+i)^2}+\dots\dots\dots+\frac{1}{(1+i)^n}.$$

The sum of this geometric series is

$$a_{\overline{n}|}=\frac{1-v^n}{i}=\frac{1-(1+i)^{-n}}{i} \tag{19}$$

and its values are given in Table 35.

Example 12.—To find the present value at 3% of an annual payment of $56,325 at the end of each year for thirty years.

Referring to Table 35, it is seen that $a_{\overline{30}|}$ at 3% is 19.6004413, and therefore the equired present value is

$$19.6004413\times\$56,325=\$1,103,994.86.$$

While the above demonstration relates to an annuity of 1 per annum, payable at the end of each year, the same principles apply to finding the present value of an annuity of 1 per annum, payable in p installments during each year. The present value of such an annuity is designated by the symbol $a_{\overline{n}|}^{(p)}$, and its value is represented by the following formula:

$$a_{\overline{n}|}^{(p)}=\frac{1-v^n}{p[(1+i)^{1/p}-1]}=\frac{1-(1+i)^{-n}}{p[(1+i)^{1/p}-1]}. \tag{20}$$

In formulas (19) and (20) the values of the annuities are expressed in terms of the effective rate i. If $(1+i)$ is replaced by $(1+j/m)^m$ in accordance with formula (2), there result the present values of the same annuities expressed as follows in terms of the nominal rate of interest j, with frequency of conversion m:

$$a_{\overline{n}|}=\frac{1-(1+j/m)^{-mn}}{(1+j/m)^m-1}, \tag{21}$$

and

$$a_{\overline{n}|}^{(p)}=\frac{1-(1+j/m)^{-mn}}{p[(1+j/m)^{m/p}-1]}. \tag{22}$$

Fundamental relations between the present value and the amount of an annuity.—Since $a_{\overline{n}|}$ and $s_{\overline{n}|}$ are the values of the same annuity upon two dates differing by n years, it follows by the principle of reduction of values from one date to another, explained on page 95, that

$$a_{\overline{n}|}=v^n s_{\overline{n}|},$$

$$s_{\overline{n}|}=(1+i)^n a_{\overline{n}|},$$

and in like manner that

$$a^{(p)}_{\overline{n}|}=v^n s^{(p)}_{\overline{n}|},$$

$$s^{(p)}_{\overline{n}|}=(1+i)^n a^{(p)}_{\overline{n}|}.$$

As tables are not published giving the values of $a^{(p)}_{\overline{n}|}$ and $s^{(p)}_{\overline{n}|}$, when p is different from 1, it is desirable for purposes of computation to express a relation between these functions and the tabulated functions $a_{\overline{n}|}$ and $s_{\overline{n}|}$. This can easily be done by accumulating to the end of each year the p payments of $1/p$ which in $a^{(p)}_{\overline{n}|}$ and $s^{(p)}_{\overline{n}|}$ are distributed at equal intervals through the year. By formula (11) this accumulation to the end of each year will be equal to

$$s^{(p)}_{\overline{1}|}=\frac{i}{p[(1+i)^{1/p}-1]}=\frac{i}{j_{(p)}}.$$

This converts the annuity into one with annual rent $s^{(p)}_{\overline{1}|}$ payable at the end of each year for n years. Therefore

$$\boldsymbol{a^{(p)}_{\overline{n}|}=s^{(p)}_{\overline{1}|}\,a_{\overline{n}|}}, \qquad (23)$$

$$\boldsymbol{s^{(p)}_{\overline{n}|}=s^{(p)}_{\overline{1}|}\,s_{\overline{n}|}}. \qquad (24)$$

The most frequent intervals in practice are semiannual, quarterly, and monthly, and to meet this requirement the values of $s^{(2)}_{\overline{1}|}$, $s^{(4)}_{\overline{1}|}$, and $s^{(12)}_{\overline{1}|}$ are given below for various rates of interest.

Values of $s^{(p)}_{\overline{1}|}=i/j_{(p)}=\dfrac{i}{p[(1+i)^{1/p}-1]}$

p	1½%	1¾%	2%	2¼%	2½%	2¾%	3%
2	1.00373604	1.00435603	1.00497525	1.00559371	1.00621142	1.00682837	1.00744458
4	1.00560755	1.00653878	1.00746906	1.00839839	1.00932677	1.01025422	1.01118072
12	1.00685652	1.00799571	1.00913389	1.01027107	1.01140725	1.01254243	1.01367662

p	3½%	4%	4½%	5%	5½%	6%	7%
2	1.00867475	1.00990195	1.01112621	1.01234754	1.01356596	1.01478151	1.01720402
4	1.01303094	1.01487744	1.01672026	1.01856942	1.02039495	1.02222688	1.02588002
12	1.01594203	1.01820351	1.02046109	1.02271479	1.02496465	1.02721070	1.03169143

Example 13.—What is the present value of an annuity for 30 years at effective rate 3%, payable in monthly installments of $25?

By formula (23) with $n=30$, $p=12$, $i=.03$,

$$a^{(12)}_{\overline{30}|}=s^{(12)}_{\overline{1}|}\cdot a_{\overline{30}|}=1.01367662\times 19.6004413=19.86850909.$$

Therefore the present value of a similar annuity of $25 per month, or with annual rent of $300, is

$$19.86850909\times \$300=\$5{,}960.55.$$

The annuity which 1 will purchase.—The present value $a_{\overline{n}|}$ of an annuity may be viewed as the principal which, invested at the effective rate of interest i, will provide a payment of 1 at the end of each year and will not be exhausted until the end of the nth year; in other words, $a_{\overline{n}|}$ is just sufficient to purchase an n year annuity of annual rent 1 payable at the end of each year. By proportion it appears that 1 will purchase an n year annuity of annual rent $1/a_{\overline{n}|}$ payable at the end of each year. This quantity may be described as the annuity which 1 will purchase, and its value is

$$\frac{1}{a_{\overline{n}|}}=\frac{i}{1-v^n}=\frac{i}{1-(1+i)^{-n}}. \tag{25}$$

This function is of great importance in annuity bond calculations, and its values are given for 60 terms and different rates of interest in Table 36, on pages 126 and 127.

Example 14.—To find the uniform annual payment which in 20 years will discharge a loan of $100,000, including both principal and interest, at 5 per cent compounded annually.

In this case $n=20$, $i=.05$; employing formula (25) and referring to Table 36, it follows that a loan of 1 will be discharged, both principal and interest, by an annual payment of

$$\frac{1}{a_{\overline{20}|}}=.0802426;$$

hence the loan of $100,000 will be likewise discharged by an annual payment of

$$.0802426\times\$100,000=\$8,024.26.$$

By similar reasoning it follows that 1 will purchase an immediate annuity-certain with annual rent $1/a_{\overline{n}|}^{(p)}$, payable in p installments each year. The value of each *periodical installment* is

$$\frac{1}{pa_{\overline{n}|}^{(p)}}=\frac{(1+j/m)^{m/p}-1}{1-(1+j/m)^{-mn}}, \tag{26}$$

where interest is at the nominal rate j with frequency of conversion m. When $m=1$, the nominal rate $j_{(1)}$ becomes the effective rate i. When the conversion of interest occurs with the same frequency as the periodical payment, that is, when $m=p$, formula (26) reduces to the important particular case

$$\frac{1}{pa_{\overline{n}|}^{(p)}}=\frac{j/p}{1-(1+j/p)^{-np}}=\frac{1}{a_{\overline{np}|}}, \tag{27}$$

where $a_{\overline{np}|}$ is to be taken at j/p per cent.

Example 15.—To find the half yearly payment at 5% compounded semiannually which will discharge both principal and interest on a loan of $100,000 in three years.

By formula (27) with $n=3$, $p=2$, a loan of 1 will be discharged, both principal and interest, in three years by a semiannual payment of

$$\frac{1}{a_{\overline{6}|}\ (\text{taken at } 2\tfrac{1}{2}\%)}=.1815500,$$

and the loan of $100,000 will be discharged in like manner by

$$.1815500\times\$100,000=\$18,155.00.$$

Installment annuity loan.—The preceding example shows how the function $1/a_{\overline{n}|}$ may be employed to determine the periodical fixed payment which in n years will discharge both principal and interest on a loan. It is to be noted particularly that the lender receives interest throughout the term of the loan on all *outstanding* principal. The following schedule, based on the above example, illustrates the progress of the loan.

SCHEDULE I.—*Showing repayment of principal and interest on a loan of $100,000 by six equal semiannual payments, each of $18,155; interest 5 per cent, compounded semiannually.*

Year.	Principal outstanding at beginning of interval.	Interest for interval.	Semiannual payment.	Principal repayment for interval.
$\frac{1}{2}$	$100,000.00	$2,500.00	$18,155.00	$15,655.00
1	84,345.00	2,108.63	18,155.00	16,046.37
$1\frac{1}{2}$	68,298.63	1,707.47	18,155.00	16,447.53
2	51,851.10	1,296.28	18,155.00	16,858.72
$2\frac{1}{2}$	34,992.38	874.81	18,155.00	17,280.19
3	17,712.19	442.81	18,155.00	17,712.19
Totals	357,199.30	8,930.00	108,930.00	100,000.00

The initial invested principal of $100,000 earns $2,500 interest during the first half year; the first payment of $18,155.00 takes care of this and there remains a balance of $15,655.00 which goes to reduce the outstanding principal to $84,345.00, beginning with the second half year. This process is repeated until the end of the third year, when the last outstanding principal is retired. When preparing such a schedule, the work can be checked by adding the columns. It is evident from the nature of the calculations that, for example, if the first row were omitted from this schedule, the remaining five would represent the schedule for a loan of $84,345.00 on the same terms as the original loan, except that it would be discharged in two and one-half years by five equal semiannual payments. It must therefore be the present value of the five payments, that is,

$$a_{\overline{5}|} \times \frac{\$100{,}000}{a_{\overline{6}|}} = \$84{,}345.00,$$

where the annuities are taken at $2\frac{1}{2}$ per cent. Similarly, by successively employing $a_{\overline{4}|}$, $a_{\overline{3}|}$, $a_{\overline{2}|}$, and $a_{\overline{1}|}$, all at $2\frac{1}{2}$ per cent, as multipliers, the figures in the first column of principal outstanding at the beginning of the interval could be obtained. When these are known, the figures in the second column are obtained by multiplying the corresponding figures in the first column by the interest rate for the interval, .025; in the fourth, by successive subtractions of the figures in the first; and in the third, by adding those in the second to those in the fourth as a check.

Generalization of the annuity loan.—The preceding discussion can most easily be generalized by considering the loan of $a_{\overline{n}|}$ dollars where both principal and interest at *effective rate i per annum* are discharged by equal annual installments of 1 at the end of each year for n years. The initial principal is $a_{\overline{n}|}$; the interest, $ia_{\overline{n}|} = 1 - v^n$; the annual payment, 1, of which $1 - (1 - v^n) = v^n$ is applied to repayment of principal. But $a_{\overline{n}|} - v^n = a_{\overline{n-1}|}$; hence the outstanding principal at the beginning of the second year is $a_{\overline{n-1}|}$, as might have been predicted in advance. A repetition of this process leads to the following schedule:

Schedule II.—*Showing repayment of principal and interest at effective rate i per annum on a loan of $a_{\overline{n}|}$ by equal annual payments of 1 at the end of each year for n years.*

Year.	Principal outstanding at beginning of year.	Interest due at end of year.	Annual payment at end of year.	Principal repaid at end of year.
1	$a_{\overline{n}\|}$	$1-v^n$	1	v^n
2	$a_{\overline{n-1}\|}$	$1-v^{n-1}$	1	v^{n-1}
3	$a_{\overline{n-2}\|}$	$1-v^{n-2}$	1	v^{n-2}
:	:	:	:	:
k	$a_{\overline{n-k+1}\|}$	$1-v^{n-k+1}$	1	v^{n-k+1}
:	:	:	:	:
n	$a_{\overline{1}\|}$	$1-v$	1	v
Totals	$(n-a_{\overline{n}\|})/i$	$n-a_{\overline{n}\|}$	n	$a_{\overline{n}\|}$

Since this is a schedule for a loan of $a_{\overline{n}|}$, if each item in it, apart from those in the column headed "year," is divided by $a_{\overline{n}|}$ and multiplied by L, there results the corresponding schedule for a loan of L dollars.

For example, the items on a loan of L dollars for the kth year would be

$$\boldsymbol{La_{\overline{n-k+1}|}/a_{\overline{n}|}}, \quad \boldsymbol{L(1-v^{n-k+1})/a_{\overline{n}|}}, \quad \boldsymbol{L/a_{\overline{n}|}}, \quad \boldsymbol{Lv^{n-k+1}/a_{\overline{n}|}}. \qquad (28)$$

There are some curious properties revealed by the above schedule, among which the following may be pointed out. The principal repayments on an annuity loan increase in geometrical progression, the factor being $1+i$. The sum of these repayments is $a_{\overline{n}|}$; the sum of the annual payments is n; the total interest is $n-a_{\overline{n}|}$; and the check on the first and second columns shows that

$$i(a_{\overline{1}|}+a_{\overline{2}|}+ \ldots\ldots\ldots + a_{\overline{n}|}) = n - a_{\overline{n}|}.$$

It is apparent that most of the items in the schedule can be filled in directly from the $a_{\overline{n}|}$ and v^n tables. Having thus filled in each number, it would be necessary only to multiply each item by $L/a_{\overline{n}|}$ to obtain the corresponding schedule for a loan of L.

If in the preceding discussion *year* is replaced by *interval*, the schedule may be made to apply to loans repaid by equal installments at the end of each interval.

Relation between annuity which 1 will purchase and sinking fund which will amount to 1.—The important relation

$$\frac{1}{a_{\overline{n}|}} = \frac{1}{s_{\overline{n}|}} + i \qquad (29)$$

can easily be verified by substitution of the values of $1/a_{\overline{n}|}$ and $1/s_{\overline{n}|}$ expressed in terms of i, by formulas (25) and (15).

The relation (29) merely expresses the fact that the annual rent, $1/a_{\overline{n}|}$ on the annuity which 1 will purchase, must include, not only the interest i on the unit so invested, but also a sinking fund, $1/s_{\overline{n}|}$, which will accumulate to the invested unit at the end of the term of the annuity.

Application to bond calculations.—An important application of the theory of compound interest and annuities arises in the valuation of bonds. First to determine the value of a bond issue redeemable in one sum on a given date, with interest, or dividends, on the outstanding bonds at rate g, and all computed, or *valued*, so as to yield the purchaser a given effective rate of interest i. Consider an issue of $100,000 highway bonds, denomination $500, dated January 1, 1914, maturing January 1, 1948, interest 5 per cent, payable annually.

The annual interest, or dividends, on these bonds is 5 per cent, and the bonds are redeemed at the end of 34 years. Suppose an intending purchaser desires to pay a price which will yield a net income of 3 per cent on his investment; how much ought he to bid? This is the nature of the general problem. If the purchaser desires to realize 5 per cent on his investment, he must bid $100,000 for the bonds, or $1 for each dollar to be redeemed. If, however, he is content with 3 per cent, more than $100,000 must be paid for the bonds, that is, more than $1 for each dollar to be redeemed. In this case the bonds are said to be bought at a *premium*; if less than $1 is paid for each dollar to be redeemed, the bonds are said to be bought at a *discount*.

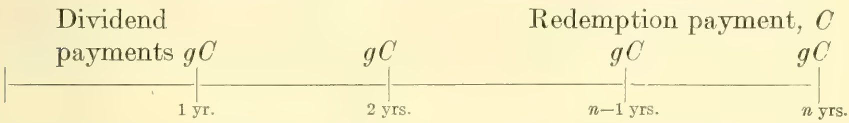
In the general case, let C denote the price to be paid on redemption; i, the effective rate of interest employed in the valuation of the bonds, which is the *net income* rate to the purchaser; g, the *ratio* of the dividend per annum to C; n, the number of years after which the bonds are redeemed; K, the present value of C, due n years hence, at the effective rate of interest i; and A, the present value of, or bid on, the bonds.

In the above illustration $C=100{,}000$, and $n=34$. The dividend or interest per annum is 5,000. Hence $g=5{,}000/100{,}000=.05$.

Returning to the general problem, the value of the bonds, so far as the purchaser or holder is concerned, consists of two parts:

1. *The annual interest, or dividend, to be received.*
2. *The sum to be redeemed at the end of n years.*

Hence, to find the present value, A, of the bonds, the present value of each of these parts must be determined and added together. The interest per unit of the redemption price C is, by definition, g; if the interest on 1 unit is g, the interest on C units is gC. Hence at the end of every year for n years the holder will receive gC units.



It is evident that these interest or dividend payments of gC at the end of every year constitute an immediate annuity-certain of annual rent gC and term of n years. The value of such an annuity with annual rent 1 is $a_{\overline{n}|}$; hence the value of the annuity with annual rent gC is

$$gC\,a_{\overline{n}|},$$

where $a_{\overline{n}|}$ is to be taken at the rate of interest i *to be employed in the valuation* of the bonds, a rate which in general is different from g, the rate of dividend.

By formula (5), the present value of the sum C, to be redeemed in n years, is $v^n=C$.

Adding these parts together, the result is

$$A=v^nC+gCa_{\overline{n}|}.$$

Substituting in this relation the value of $a_{\overline{n}|}$ given by formula (19), it follows that

$$A=v^nC+\frac{g}{i}(C-v^nC).$$

Since, by definition, $K=v^nC$, the *bid* is given by

$$\boldsymbol{A=K+\frac{g}{i}(C-K)} \qquad (30)$$

and the *premium* by

$$\boldsymbol{A-C=(C-K)\frac{(g-i)}{i}}. \qquad (31)$$

If in formula (31) the *total sum to be redeemed is regarded as unity*, then $C=1$ and $K=v^n$, the present value of 1 due in n years, and there results

$$A=1+\frac{(1-v^n)}{i}(g-i)=1+(g-i)a_{\overline{n}|}. \tag{32}$$

In this formula $a_{\overline{n}|}$ is taken at i per cent, and gives the bid on a bond where the sum to be redeemed is 1. Denoting the excess of A over 1 by k, which is called the *premium*, formula (32) becomes

$$k=(g-i)a_{\overline{n}|}^{i\%}, \tag{33}$$

where the i per cent over the symbol $a_{\overline{n}|}$ means that the function is to be taken from the i per cent annuity table.

This is the fundamental formula in bond calculations. It admits of a very simple interpretation, for it states that the premium on a bond is equal to the present value of an n year annuity at i per cent whose annual rent is the excess $(g-i)$ of the nominal rate of dividend of the bond over the effective rate of interest i, desired to be realized by the investor.

					Unit redeemed, 1
Unit invested, 1		i (1 yr.)	i (2 yrs.)	i ($n-1$ yrs.)	i (n yrs.)
Premium,	k	$g-i$	$g-i$	$g-i$	$g-i$

The dividend paid each year on each unit of the bond to be redeemed is g, which may be divided into two parts, i and $g-i$. For the first part the investor pays 1 and in return receives interest of i each year and the 1 is redeemed at the end of n years. For the second part the investor pays the premium, $k=(g-i)a_{\overline{n}|}$, and this is repaid, both principal and interest at rate i, in n equal annual installments of $(g-i)$. A portion of each installment goes toward the repayment of the premium k which is eventually reduced to zero. This is called the *amortization* or *writing off of the premium.*

It is thus seen that, if k is positive, the bond is bought at a premium; and if k is negative, it is bought at a discount. Since $a_{\overline{n}|}$ is always positive, it appears from formula (33) that the sign of k will be positive when g is greater than i, or *when the rate of dividend is greater than the rate of interest used in valuation;* conversely, when g is less than i, k is negative.

Example 16.—To find the bid on the highway bond mentioned on page 104, on the hypothesis that the purchaser wishes to realize 3% on his investment.

Consider a dollar (unit) of the loan C=100,000. Here $n=34$, $g=.05$, $i=.03$, and by formula (33),

$$k=(.05-.03)a_{\overline{34}|}^{3\%}=.02\times21.1318367=.422636734,$$

or the premium is slightly over 42 cents on the dollar. Since for each dollar of the loan the purchaser must pay $1.422636734, for the whole loan of $100,000 he must pay

$$1.422636734\times\$100{,}000=\$142{,}263.67.$$

Dividends payable and interest convertible semiannually.—When the net income interest rate desired by the investor is nominal, say $j_{(m)}$, and the dividends per unit of the sum to be redeemed are paid in m equal installments, g/m, during the year, it is evident that it is a case of m times n intervals with g/m as dividend and j/m as the *effective rate of interest per interval.* Hence formula (33) becomes

$$k=\frac{(g-j)}{m}a_{\overline{mn}|}^{j/m\%}. \qquad (34)$$

In particular, if the net income is $j_{(2)}$, and the dividend payments are semiannual,

$$k=\frac{(g-j)}{2}a_{\overline{2n}|}^{j/2\%}. \qquad (35)$$

This formula provides for the valuation of all bonds, redeemed in one sum at the end of a term of n years and with semiannual dividends. Particular attention is called to the fact that the annuity must be taken for the term $2n$, and at the rate of interest $j/2$.

Example 17.—What is the bid on $100,000 highway 5% bonds maturing at the end of 3 years, interest payable semiannually, to net purchaser a nominal rate of 4% convertible half-yearly?

Here $n=3$, $g=.05$, $j=.04$, $m=2$, and formula (35) gives

$$k=\frac{(.05-.04)}{2}a_{\overline{6}|}^{2\%}=.005\times5.6014309=.0280071545.$$

Hence the premium on $100,000 is $2,800.72, and the corresponding bid is $102,800.72. The progress of this bond loan is illustrated in the following schedule.

SCHEDULE III.

Year.	Book value or principal at beginning of half-year.	Semiannual interest of 2%.	Semiannual dividend of 2½% on bonds.	Amortization of premium at end of half-year.	Redemption payment at end of half-year.
½	$102, 800. 72	$2, 056. 01	$2, 500. 00	$443. 99	0. 00
1	102, 356. 73	2, 047. 13	2, 500. 00	452. 87	0. 00
1½	101, 903. 86	2, 038. 08	2, 500. 00	461. 92	0. 00
2	101, 441. 94	2, 028. 84	2, 500. 00	471. 16	0. 00
2½	100, 970. 78	2, 019. 42	2, 500. 00	480. 58	0. 00
3	100, 490. 20	2, 009. 80	2, 500. 00	490. 20	$100, 000. 00
Totals	609, 964. 23	12, 199. 28	15, 000. 00	2, 800. 72	100, 000. 00

At the outset the holder has an investment of $102,800.72 upon which, at 2 per cent, at the end of the first half-year, $2,056.01 interest is due; the dividend payment of $2,500.00 then made on the bonds provides for this interest and a balance of $443.99 remains, which is applied to *amortize* or *write off* the premium so that the *book-value*, or invested principal, is reduced to $102,356.73 at the beginning of the second half-year. This process continues for three years until the entire premium of $2,800.72 is written off and the bonds are redeemed by the payment of $100,000. The various columns are added and the checks upon these totals are obvious.

Example 18.—What is the bid on $100,000 highway 3% bonds maturing at the end of 3 years, interest payable semiannually, to net purchaser a nominal rate of 4% convertible half-yearly?

Here $n=3$, $g=.03$, $j=.04$, $m=2$, and formula (35) gives

$$k=\frac{(.03-.04)}{2}a_{\overline{6}|}^{2\%}=-.005\times5.6014309=-.0280071545.$$

Hence the *discount* on $100,000 is $2,800.72, and the corresponding bid is $97,199.28. The progress of this bond loan is illustrated in the following schedule.

SCHEDULE IV.

Year.	Book value or principal at beginning of half-year.	Semiannual interest of 2%.	Semiannual dividend of 1½% on bonds.	Accumulation of discount at end of half-year.	Redemption payment at end of half-year.
½	$97,199.28	$1,943.99	$1,500.00	$443.99	0.00
1	97,643.27	1,952.87	1,500.00	452.87	0.00
1½	98,096.14	1,961.92	1,500.00	461.92	0.00
2	98,558.06	1,971.16	1,500.00	471.16	0.00
2½	99,029.22	1,980.58	1,500.00	480.58	0.00
3	99,509.80	1,990.20	1,500.00	490.20	$100,000.00
Totals	590,035.77	11,800.72	9,000.00	2,800.72	100,000.00

In this case the holder has an initial investment of $97,199.28, and at the end of the first half-year 2 per cent interest, or $1,943.99, is due. The dividend payment of $1,500.00, then made on the bonds, is *not sufficient* to provide for this interest, and the difference of $443.99 is added to the principal and determines the *book value* at the beginning of the second half-year. This is called the *accumulation* or *writing on* of discount. By continuing this process for three years the entire discount of $2,800.72 is written on the initial principal, and the book value, $100,000, is then redeemed. The totals of the several columns may be used to check the numerical work.

Valuation of bonds redeemed in installments.—For the valuation of bonds which are not redeemed in one sum, but in a series of installments, first consider the simpler case where the dividend payments are annual and the rate of interest is the effective rate i.

Let $C_1, C_2, \ldots C_r$, denote the successive installments by which the bonds are to be redeemed;

$n_1, n_2, \ldots n_r$, the respective number of years after which the successive installments become due;

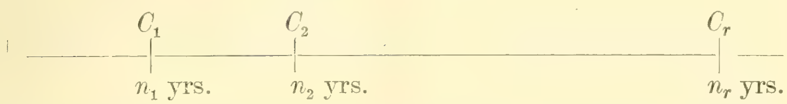
$K_1, K_2, \ldots K_r$, the present values, at the effective rate of interest i, of

C_1 due n_1 years hence,
C_2 due n_2 years hence,
. . . .
C_r due n_r years hence;

g, the fixed rate of dividend to be paid on the *outstanding* bonds;

i, the effective rate of interest employed in the valuation of the bonds, which is the *net income* rate to the purchaser;

and $A_1, A_2, \ldots\ldots A_r$, the present values, at the effective rate i, of the separate installments *with their respective dividends.*



Each installment redeemed may be regarded as furnishing a distinct problem under formula (30) so that, in order to value the entire bond issue, it may be treated as made up of r distinct issues and, after finding the value of each one, they may be added together for the value or bid on the total issue.

By formula (30) in the case of a single issue of C_1 at *net income* rate i, dividend rate g, due in n_1 years, the present value, or bid, A_1, is:

$$A_1 = K_1 + (g/i)\ (C_1 - K_1).$$

Similarly,

$$A_2 = K_2 + (g/i)\ (C_2 - K_2),$$

$$\ldots\ldots\ldots\ldots\ldots\ldots,$$

$$A_r = K_r + (g/i)\ (C_r - K_r).$$

Adding,

$$(A_1 + A_2 + \ldots\ldots + A_r) = (K_1 + K_2 + \ldots\ldots + K_r)$$
$$+ (g/i)[(C_1 + C_2 + \ldots\ldots + C_r) - (K_1 + K_2 + \ldots\ldots + K_r)].$$

The total sum to be redeemed, $C_1 + C_2 + \ldots\ldots + C_r$, is denoted by C; the total present value of C_1 in n_1 years, C_2 in n_2 years, and so on, which by definition is equal to $K_1 + K_2 + \ldots\ldots + K_r$, by K; and the total value of the issue, $A_1 + A_2 + \ldots\ldots + A_r$, by A; then for the bid there results

$$\boldsymbol{A = K + (g/i)\ (C - K)}, \tag{36}$$

and for the premium,

$$\boldsymbol{A - C = (C - K)\ (g - i)/i}. \tag{37}$$

It thus appears that formulas (30) and (31), which were derived before for the case of a bond issue redeemed in one sum, hold also for the more general issue redeemed in any number of installments.

Installment bonds when total sum to be redeemed is 1.— When 1 is the total sum to be redeemed, that is, when $C = 1$, formula (37) becomes

$$\boldsymbol{A - 1 = (1 - K)\ (g - i)/i}, \tag{38}$$

where A is the value of each unit of the sum to be redeemed, and K is the present value of the various parts of the unit at effective rate i due in $n_1, n_2, \ldots n_r$ years. Letting $A-1=k$, formula (38) becomes

$$\boldsymbol{k=(1-K)\ (g-i)/i.} \tag{39}$$

The premium is positive if g is greater than i, and negative, or a discount, if g is less than i; for the first factor $(1-K)$ can not be negative, as K by definition is the *present value* of a series of future payments whose sum is 1, and hence their present discounted value must be less than 1. This shows in all cases that a bond issue must be bought at a *premium*, if it is valued at a *lower* rate i than the rate of dividend g; and at a discount, if it is valued at a higher rate i than the rate of dividend g.

Serial bonds.—To apply the general formula (39) to the case of a bond issue redeemed by n equal annual installments, consider a unit of the total sum to be redeemed. Since this unit is to be redeemed in n equal installments over n years, the annual portion redeemed is $1/n$.

$1/n$ $1/n$ $1/n$ $1/n$

1 yr. 2 yrs. 3 yrs. n yrs.

The present value, K, of these n installments is clearly the value of an annuity of annual rent $1/n$; hence

$$K=a_{\overline{n}|}\times 1/n=a_{\overline{n}|}/n.$$

Substituting this value of K in formula (39), the following formula is obtained:

$$\boldsymbol{k=(1-a_{\overline{n}|}/n)\ (g-i)/i.} \tag{40}$$

Example 19.—What is the bid on $100,000 highway 4% serial bonds maturing in 20 equal annual installments, to net the purchaser an effective rate of 3%?

Here $n=20$, $g=.04$, $i=.03$, and $a^{3\%}_{\overline{20}|}=14.8774749$; consequently

$$k=(1-14.8774749/20)(.04-.03)/.03$$
$$=(1-.743873745)\times 1/3=.256126255\times 1/3=.085375418.$$

Hence the bid on $100,000 is

$$1.085375418\times \$100{,}000=\$108{,}537.54.$$

Extension of formulas to case when dividends are payable and interest is convertible *m* times per annum.—Formula (36) assumes that dividends are payable once a year and that the effective rate of interest is i per annum. Replacing *year* by *interval* and assuming dividends to be paid at the end of each interval and the rate of interest realized by the investor a nominal rate convertible m times a year, formula (36) still applies, if the present value K of the several installments to be redeemed is calculated at the effective rate j/m per interval, and the dividend per unit of the sum to be redeemed is taken at the rate g/m per interval. The formula is unchanged in form since m cancels out in the ratio g/m to j/m.

General formula for valuation of bonds.—Assume that:

1. The bonds are redeemed in r equal installments.
2. The first redemption of bonds is made at the end of f years.
3. The remaining $r-1$ bond redemptions are made at intervals of t years.
4. The annual rate of dividend is g paid in m equal installments.
5. The bond issue is valued at the nominal rate $j_{(m)}$.

First find the present value, A, of an issue of the above type where $C=1$. The value of a similar total issue of C is then found by multiplying A by C. Since the unit fund is redeemed in r equal installments, each one will be $1/r$.

Redemption payments $1/r$ $1/r$ $1/r$ $1/r$

f years t yrs. t yrs.

The total term of the issue is seen to be $f+(r-1)t$ years. As in preceding extension of formulas when dividends are payable and interest is convertible m times per annum, apply formula (36) to each installment of $1/r$ in the unit issue and the formula for the value of k, the premium per unit of the total sum to be redeemed, may readily be obtained. Expressed in terms of annuities, it appears as follows:

$$k=\left[1-\frac{a_{\overline{m(f+tr)}|}-a_{\overline{mf}|}}{ra_{\overline{mt}|}}\right](g-j)/j \qquad \text{at rate } j/m. \tag{41}$$

The annuity present values in this formula must be computed at the rate of interest j/m. The most common case in practice is where the dividends are paid semiannually. Here $m=2$, and formula (41) becomes:

$$k=\left[1-\frac{a_{\overline{2(f+tr)}|}-a_{\overline{2f}|}}{ra_{\overline{2t}|}}\right](g-j)/j \qquad \text{at rate } j/2. \tag{42}$$

The last two formulas are very general in their application and have the advantage that when employed in practical computations it is necessary to consult only a table of values of $a_{\overline{n}|}$.

Example 20.—To find the bid on \$1,100,000 highway bonds, interest 5% payable semiannually, dated January 1, 1914, maturing \$100,000 on January 1, 1922, 1924, 1926, 1928, 1930, 1932, 1934, 1936, 1938, 1940, and 1942, to net the purchaser a nominal rate of 4%, compounded semiannually, on his investment.

Here $f=8$, $t=2$, $r=11$, $g=.05$, $m=2$, and $j_{(2)}=.04$. Accordingly, $m(f+tr)=60$, $mf=16$, and $mt=4$. Substituting in formula (42),

$$k=\left[1-\frac{a_{\overline{60}|}-a_{\overline{16}|}}{11\times a_{\overline{4}|}}\right](.05-.04)/.04 \qquad \text{at } 2\%.$$

Entering Table 35 with 2% for the values of the annuities and numbering the successive steps for convenience of explanation, the calculation may be outlined as follows:

$$a_{\overline{60}|}=34.7608867 \quad (1)$$
$$a_{\overline{16}|}=13.5777093 \quad (2)$$
$$a_{\overline{60}|}-a_{\overline{16}|}=21.1831774 \quad (3)$$
$$(3)\div 11= 1.9257434 \quad (4)$$
$$a_{\overline{4}|}= 3.8077287$$
$$(4)\div a_{\overline{4}|}= .5057460 \quad (5)$$
$$\text{Complement of } (5)=1-(5)= .4942540 \quad (6)=\text{first factor}$$
$$(.05-.04)/.04= .25 \quad (7)=\text{second factor}$$
$$k=(6)\times(7)= .1235635.$$

The bid on one dollar is $1+k=1.1235635$; consequently the bid on the whole issue is

$$1.1235635\times\$1,100,000=\$1,235,919.85.$$

Example 21.—To find the price of $100,000 highway bonds, interest 5%, semiannual, dated January 1, 1914, maturing $50,000 January 1, 1917, and $50,000 January 1, 1919, to net the investor 4% compounded semiannually.

In this case $f=3$, $r=2$, $t=2$, $m=2$, $g=.05$, $j=.04$, and, substituting as in the preceding example, the required price is found to be $103,646.00. The progress of the loan is indicated in the following schedule.

SCHEDULE V.

Year.	Book value or principal at beginning of half-year.	Semiannual interest of 2%.	Semiannual dividend of $2\frac{1}{2}$% on bonds.	Amortization of premium at end of half-year.	Redemption payment at end of half-year.
$\frac{1}{2}$	$103, 646. 00	$2, 072. 92	$2, 500. 00	$427. 08	0. 00
1	103, 218. 92	2, 064. 38	2, 500. 00	435. 62	0. 00
$1\frac{1}{2}$	102, 783. 30	2, 055. 67	2, 500. 00	444. 33	0. 00
2	102, 338. 97	2, 046. 78	2, 500. 00	453. 22	0. 00
$2\frac{1}{2}$	101, 885. 75	2, 037. 72	2, 500. 00	462. 28	0. 00
3	101, 423. 47	2, 028. 47	2, 500. 00	471. 53	$50, 000. 00
$3\frac{1}{2}$	50, 951. 94	1, 019. 04	1, 250. 00	230. 96	0. 00
4	50, 720. 98	1, 014. 42	1, 250. 00	235. 58	0. 00
$4\frac{1}{2}$	50, 485. 40	1, 009. 71	1, 250. 00	240. 29	0. 00
5	50, 245. 11	1, 004. 89	1, 250. 00	245. 11	50, 000. 00
Totals	817, 699. 84	16, 354. 00	20, 000. 00	3, 646. 00	100, 000. 00

Extension of term of tables.—It sometimes happens in applying formula (42) that the value of $2(f+tr)$ is greater then the term given in the tables. In example 20 one of the required annuity values was $a_{\overline{60}|}$ but, if the interval between redemptions had been three years instead of two, $2(f+tr)=82$ would have called for the value of an annuity $a_{\overline{82}|}$ beyond the limits of the tables. It is easy, however, to extend these limits by making use of the following obvious relations:

$$v^{m+n}=v^m v^n, \qquad (43)$$

$$(1+i)^{m+n}=(1+i)^m(1+i)^n, \qquad (44)$$

$$a_{\overline{m+n}|}=[1-v^m v^n]/i, \qquad (45)$$

$$a_{\overline{m+n}|}=a_{\overline{m}|}+v^m a_{\overline{n}|}, \qquad (46)$$

$$s_{\overline{m+n}|}=[(1+i)^m(1+i)^n-1]/i, \qquad (47)$$

$$s_{\overline{m+n}|}=(1+i)^n s_{\overline{m}|}+s_{\overline{n}|}. \qquad (48)$$

Example 22.—To find $s_{\overline{94}|}$ at $1\frac{1}{2}\%$ when the limit of the tables is 60 years or terms. Applying formula (47) there results

$$s_{\overline{94}|}=s_{\overline{60+34}|}=\frac{(1.015)^{60+34}-1}{.015}=\frac{(1.015)^{60}\times(1.015)^{34}-1}{.015}$$

$$=\frac{2.4432198\times1.6589964-1}{.015}=203.5528568.$$

By formula (48)

$$s_{\overline{94}|}=s_{\overline{60+34}|}=(1.015)^{34}\cdot s_{\overline{60}|}+s_{\overline{34}|}$$

$$=1.6589964\times96.2146517+43.9330915=203.5528523.$$

The correct value of $s_{\overline{94}|}$ at $1\frac{1}{2}\%$ to seven places of decimals is 203.5528497; so the above method may be regarded as giving the correct value to about five places of decimals. In most practical cases this will be sufficiently accurate.

Valuation of serial bonds bearing semiannual dividends.—The most common type of serial bond bears semiannual dividends and is redeemed in equal *annual* installments, the first of which is paid at the end of the first year. Formula (42) lends itself directly to the valuation of this bond at a nominal rate of interest j convertible twice a year. In this case $f=t=1$, $r=n$, and

$$k=\left[1-\frac{a_{\overline{2n+2}|}-a_{\overline{2}|}}{na_{\overline{2}|}}\right](g-j)/j \qquad \text{at rate } j/2. \qquad (49)$$

Formula (49) requires the use of a table of values of $a_{\overline{n}|}$ only. It can be put in another convenient form for computation involving the use of a table of values of $a_{\overline{n}|}$ and $s_{\overline{n}|}$. For, by formula (46), $a_{\overline{2+2n}|}=a_{\overline{2}|}+v^2a_{\overline{2n}|}$, and, since $v^2/a_{\overline{2}|}=1/(1+i)^2a_{\overline{2}|}=1/s_{\overline{2}|}$, after a simple reduction, there results

$$k=\left[1-\frac{a_{\overline{2n}|}}{ns_{\overline{2}|}}\right](g-j)/j \qquad \text{at rate } j/2. \qquad (50)$$

Example 23.—\$300,000 highway serial bonds bearing 4% interest payable semiannually, dated January 1, 1914, mature \$100,000 January 1, 1915, 1916, and 1917. What price should be paid to realize a net income of 3% compounded semiannually? Here $n=3$, $g=.04$, $j_{(2)}=.03$, and by formula (49)

$$k=\left[1-\frac{a_{\overline{8}|}-a_{\overline{2}|}}{3a_{\overline{2}|}}\right](.04-.03)/.03 \qquad \text{at } 1\tfrac{1}{2}\%$$

$$=.0575373\times1/3=.0191791,$$

therefore the price to earn 3% compounded semiannually is

$$1.0191791\times\$300,000=\$305,753.73.$$

The following schedule illustrates the progress of this loan.

SCHEDULE VI.

Year.	Book value or principal at beginning of half-year.	Semiannual interest of $1\frac{1}{2}\%$.	Semiannual dividend of 2% on bonds.	Amortization of premium at end of half-year.	Redemption payment at end of half-year.
$\frac{1}{2}$	$305,753.73	$4,586.31	$6,000.00	$1,413.69	0.00
1	304,340.04	4,565.10	6,000.00	1,434.90	$100,000.00
$1\frac{1}{2}$	202,905.14	3,043.58	4,000.00	956.42	0.00
2	201,948.72	3,029.23	4,000.00	970.77	100,000.00
$2\frac{1}{2}$	100,977.95	1,514.67	2,000.00	485.33	0.00
3	100,492.62	1,507.38	2,000.00	492.62	100,000.00
Totals	1,216,418.20	18,246.27	24,000.00	5,753.73	300,000.00

Annuity bonds.—On pages 101 to 104 the operation of a loan where both principal and interest are discharged by equal installments is fully described. It is evident that bonds may be issued on this basis and retired in accordance with the principal repayments contained in the annuity installments. Since these principal repayments are not exact multiples of the amounts or denominations in which bonds are usually issued, it is necessary to adjust the *exact* schedule so as to meet this requirement. The adjusted schedule gives an issue in which the bonds are retired year by year in increasing amounts. Examples of exact and adjusted schedules appear in the body of this bulletin on pages 16 and 17.

To finance a loan of L by an issue of annuity bonds bearing interest or dividends at rate g per annum.—The annual installment which will retire the bonds in n years and at the same time pay interest at the rate of g per cent on outstanding bonds is

$$L/a_{\overline{n}|} \qquad \text{at rate } g. \tag{51}$$

If the bonds are to bear interest of g per cent per annum, payable in p installments of g/p per cent during the year, then

$$L/a_{\overline{np}|} \qquad \text{at rate } g/p \tag{52}$$

is the periodical payment or annuity installment which will take care of interest on the bonds and retire them in n years.

Example 24.—Adjust Schedule I, page 102, to finance the same loan by an annuity bond issue of $100,000, denomination $100, bearing 5% interest, compounded semiannually, and retired in three years by six equal (nearly) semiannual annuity installments.

Referring to Schedule I on page 102, the adjustments in the last column to even multiples of $100 are easily made; a check on this work is that the adjusted column must foot up to $100,000. When the column of bond redemptions is decided upon, the other columns in the schedule are readily derived.

SCHEDULE VII.

(Schedule I adjusted to bonds of denomination $100.)

Year.	Book value or principal at beginning of half-year.	Semiannual interest of $2\frac{1}{2}$%.	Annuity installments at end of half-year.	Amortization of premium at end of half-year.	Amount of bonds retired at end of half-year.
$\frac{1}{2}$	$100, 000	$2, 500. 00	$18, 200. 00	0. 00	$15, 700
1	84, 300	2, 107. 50	18, 107. 50	0. 00	16, 000
$1\frac{1}{2}$	68, 300	1, 707. 50	18, 107. 50	0. 00	16, 400
2	51, 900	1, 297. 50	18, 197. 50	0. 00	16, 900
$2\frac{1}{2}$	35, 000	875. 00	18, 175. 00	0. 00	17, 300
3	17, 700	442. 50	18, 142. 50	0. 00	17, 700
Totals	357, 200	8, 930. 00	108, 930. 00	0. 00	100, 000

Valuation of annuity bonds.—In order to value an issue of this character, so as to yield the purchaser a net income at a rate of interest different from the rate of dividend on the bonds, it will ordinarily be necessary to value separately the several parts of the total issue in accordance with the respective dates on which they are retired. This calculation may frequently be shortened by employing formula (36). Bond tables may also be consulted to advantage. The following example and schedule respectively illustrate the calculation of the bid and progress of the loan.

Example 25.—Determine the bid on the entire issue of annuity bonds in Example 24 so as to yield the investor a net income of 4%, compounded semiannually.

Applying formula (35) successively to the several bond issues in the order in which they are retired with $g=.05$ and $j=.04$, the following premiums are found:

$76. 96
155. 32
236. 48
321. 75
407. 71
495. 73
$1, 693. 95

Accordingly, the bid on the entire issue is $101,693.95. The schedule illustrating the progress of this bond issue follows. It is constructed in the same manner as preceding bond schedules and needs no additional explanation.

SCHEDULE VIII.—*Showing the progress of an annuity bond issue of $100,000, denomination $100, bearing 5 per cent interest, compounded semiannually, and retired in three years by six equal (nearly) semiannual annuity installments. Bought to yield the investor 4 per cent, compounded semiannually.*

Year.	Book value or principal at beginning of half-year.	Semiannual interest of 2%.	Annuity installments at end of half-year.	Amortization of premium at end of half-year.	Amount of bonds retired at end of half-year.
$\frac{1}{2}$	$101, 693. 95	$2, 033. 88	$18, 200. 00	$466. 12	$15, 700
1	85, 527. 83	1, 710. 56	18, 107. 50	396. 94	16, 000
$1\frac{1}{2}$	69, 130. 89	1, 382. 62	18, 107. 50	324. 88	16, 400
2	52, 406. 01	1, 048. 12	18, 197. 50	249. 38	16, 900
$2\frac{1}{2}$	35, 256. 63	705. 13	18, 175. 00	169. 87	17, 300
3	17, 786. 76	355. 74	18, 142. 50	86. 76	17, 700
Totals	361, 802. 07	7, 236. 05	108, 930. 00	1, 693. 95	100, 000

TABLE 31.—*The accumulation of 1 at the end of n years.*

$$r^n=(1+i)^n.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	1.0150000	1.0175000	1.0200000	1.0225000	1.0250000	1.0275000	1.0300000	1
2	1.0302250	1.0353063	1.0404000	1.0455063	1.0506250	1.0557563	1.0609000	2
3	1.0456784	1.0534241	1.0612080	1.0690301	1.0768906	1.0847896	1.0927270	3
4	1.0613636	1.0718590	1.0824322	1.0930833	1.1038129	1.1146213	1.1255088	4
5	1.0772840	1.0906166	1.1040808	1.1176777	1.1314082	1.1452733	1.1592741	5
6	1.0934433	1.1097024	1.1261624	1.1428254	1.1596934	1.1767684	1.1940523	6
7	1.1098449	1.1291222	1.1486857	1.1685390	1.1886858	1.2091295	1.2298739	7
8	1.1264926	1.1488818	1.1716594	1.1948311	1.2184029	1.2423806	1.2667701	8
9	1.1433900	1.1689872	1.1950926	1.2217148	1.2488630	1.2765460	1.3047732	9
10	1.1605408	1.1894445	1.2189944	1.2492034	1.2800845	1.3116510	1.3439164	10
11	1.1779489	1.2102598	1.2433743	1.2773105	1.3120867	1.3477214	1.3842339	11
12	1.1956182	1.2314393	1.2682418	1.3060500	1.3448888	1.3847838	1.4257609	12
13	1.2135524	1.2529895	1.2936066	1.3354361	1.3785110	1.4228653	1.4685337	13
14	1.2317557	1.2749168	1.3194788	1.3654834	1.4129738	1.4619941	1.5125897	14
15	1.2502321	1.2972279	1.3458683	1.3962068	1.4482982	1.5021990	1.5579674	15
16	1.2689856	1.3199294	1.3727857	1.4276215	1.4845056	1.5435094	1.6047064	16
17	1.2880203	1.3430281	1.4002414	1.4597429	1.5216183	1.5859560	1.6528476	17
18	1.3073406	1.3665311	1.4282463	1.4925872	1.5596587	1.6295697	1.7024331	18
19	1.3269508	1.3904454	1.4568112	1.5261704	1.5986502	1.6743829	1.7535061	19
20	1.3468550	1.4147782	1.4859474	1.5605092	1.6386164	1.7204284	1.8061112	20
21	1.3670578	1.4395368	1.5156663	1.5956207	1.6795819	1.7677402	1.8602946	21
22	1.3875637	1.4647287	1.5459797	1.6315221	1.7215714	1.8163531	1.9161034	22
23	1.4083772	1.4903615	1.5768993	1.6682314	1.7646107	1.8663028	1.9735865	23
24	1.4295028	1.5164428	1.6084373	1.7057666	1.8087260	1.9176261	2.0327941	24
25	1.4509454	1.5429805	1.6406060	1.7441463	1.8539441	1.9703608	2.0937779	25
26	1.4727095	1.5699827	1.6734181	1.7833896	1.9002927	2.0245458	2.1565913	26
27	1.4948002	1.5974574	1.7068865	1.8235159	1.9478000	2.0802208	2.2212890	27
28	1.5172222	1.6254129	1.7410242	1.8645450	1.9964950	2.1374268	2.2879277	28
29	1.5399805	1.6538576	1.7758447	1.9064973	2.0464074	2.1962061	2.3565655	29
30	1.5630802	1.6828001	1.8113616	1.9493934	2.0975676	2.2566017	2.4272625	30
31	1.5865264	1.7122491	1.8475888	1.9932548	2.1500068	2.3186583	2.5000804	31
32	1.6103243	1.7422135	1.8845406	2.0381030	2.2037569	2.3824214	2.5750828	32
33	1.6344792	1.7727022	1.9222314	2.0839603	2.2588509	2.4479380	2.6523352	33
34	1.6589964	1.8037245	1.9606760	2.1308495	2.3153221	2.5152563	2.7319053	34
35	1.6838813	1.8352897	1.9998896	2.1787936	2.3732052	2.5844258	2.8138625	35
36	1.7091395	1.8674073	2.0398873	2.2278164	2.4325353	2.6554975	2.8982783	36
37	1.7347766	1.9000869	2.0806851	2.2779423	2.4933487	2.7285237	2.9852267	37
38	1.7607983	1.9333384	2.1222988	2.3291960	2.5556824	2.8035581	3.0747835	38
39	1.7872103	1.9671718	2.1647448	2.3816029	2.6195745	2.8806560	3.1670270	39
40	1.8140184	2.0015973	2.2080397	2.4351890	2.6850638	2.9598740	3.2620378	40
41	1.8412287	2.0366253	2.2522005	2.4899807	2.7521904	3.0412705	3.3598989	41
42	1.8688471	2.0722662	2.2972445	2.5460053	2.8209952	3.1249055	3.4606959	42
43	1.8968798	2.1085309	2.3431894	2.6032904	2.8915201	3.2108404	3.5645168	43
44	1.9253330	2.1454302	2.3900531	2.6618644	2.9638081	3.2991385	3.6714523	44
45	1.9542130	2.1829752	2.4378542	2.7217564	3.0379033	3.3898648	3.7815958	45
46	1.9835262	2.2211773	2.4866113	2.7829959	3.1138509	3.4830861	3.8950437	46
47	2.0132791	2.2600479	2.5363435	2.8456133	3.1916971	3.5788709	4.0118950	47
48	2.0434783	2.2995987	2.5870704	2.9096396	3.2714896	3.6772899	4.1322519	48
49	2.0741305	2.3398417	2.6388118	2.9751065	3.3532768	3.7784154	4.2562194	49
50	2.1052424	2.3807889	2.6915880	3.0420464	3.4371087	3.8823218	4.3839060	50
51	2.1368211	2.4224527	2.7454198	3.1104924	3.5230364	3.9890856	4.5154232	51
52	2.1688734	2.4648457	2.8003282	3.1804785	3.6111124	4.0987855	4.6508859	52
53	2.2014065	2.5079805	2.8563348	3.2520393	3.7013902	4.2115021	4.7904125	53
54	2.2344276	2.5518701	2.9134614	3.3252102	3.7939249	4.3273184	4.9341249	54
55	2.2679440	2.5965279	2.9717307	3.4000274	3.8887730	4.4463196	5.0821486	55
56	2.3019631	2.6419671	3.0311653	3.4765280	3.9859924	4.5685934	5.2346131	56
57	2.3364926	2.6882015	3.0917886	3.5547499	4.0856422	4.6942298	5.3916514	57
58	2.3715400	2.7352450	3.1536244	3.6347318	4.1877832	4.8233211	5.5534010	58
59	2.4071131	2.7831118	3.2166969	3.7165132	4.2924778	4.9559624	5.7200030	59
60	2.4432198	2.8318163	3.2810308	3.8001348	4.3997897	5.0922514	5.8916031	60

TABLE 31.—*The accumulation of 1 at the end of n years*—Continued.

$$r^n=(1+i)^n.$$

Years.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Years.
1	1.0350000	1.0400000	1.0450000	1.0500000	1.0550000	1.0600000	1.0700000	1
2	1.0712250	1.0816000	1.0920250	1.1025000	1.1130250	1.1236000	1.1449000	2
3	1.1087179	1.1248640	1.1411661	1.1576250	1.1742414	1.1910160	1.2250430	3
4	1.1475230	1.1698586	1.1925186	1.2155063	1.2388247	1.2624770	1.3107960	4
5	1.1876863	1.2166529	1.2461819	1.2762816	1.3069600	1.3382256	1.4025517	5
6	1.2292553	1.2653190	1.3022601	1.3400956	1.3788428	1.4185191	1.5007304	6
7	1.2722793	1.3159318	1.3608618	1.4071004	1.4546792	1.5036303	1.6057815	7
8	1.3168090	1.3685691	1.4221006	1.4774554	1.5346865	1.5938481	1.7181862	8
9	1.3628974	1.4233118	1.4860951	1.5513282	1.6190943	1.6894790	1.8384592	9
10	1.4105988	1.4802443	1.5529694	1.6288946	1.7081445	1.7908477	1.9671514	10
11	1.4599697	1.5394541	1.6228531	1.7103394	1.8020924	1.8982986	2.1048520	11
12	1.5110687	1.6010322	1.6958814	1.7958563	1.9012075	2.0121965	2.2521916	12
13	1.5639561	1.6650735	1.7721961	1.8856491	2.0057739	2.1329283	2.4098450	13
14	1.6186945	1.7316765	1.8519449	1.9799316	2.1160915	2.2609040	2.5785342	14
15	1.6753488	1.8009435	1.9352824	2.0789282	2.2324765	2.3965582	2.7590315	15
16	1.7339860	1.8729813	2.0223702	2.1828746	2.3552627	2.5403517	2.9521638	16
17	1.7946756	1.9473005	2.1133768	2.2920183	2.4848022	2.6927728	3.1588152	17
18	1.8574892	2.0258165	2.2084788	2.4066192	2.6214663	2.8543392	3.3799323	18
19	1.9225013	2.1068492	2.3078603	2.5269502	2.7656469	3.0255995	3.6165275	19
20	1.9897889	2.1911231	2.4117140	2.6532977	2.9177575	3.2071355	3.8696845	20
21	2.0594315	2.2787681	2.5202412	2.7859626	3.0782342	3.3995636	4.1405624	21
22	2.1315116	2.3699188	2.6336520	2.9252607	3.2475370	3.6035374	4.4304017	22
23	2.2061145	2.4647155	2.7521664	3.0715238	3.4261516	3.8197497	4.7405299	23
24	2.2833285	2.5633042	2.8760138	3.2250999	3.6145899	4.0489346	5.0723670	24
25	2.3632450	2.6658363	3.0054345	3.3863549	3.8133924	4.2918707	5.4274326	25
26	2.4459586	2.7724698	3.1406790	3.5556727	4.0231289	4.5493830	5.8073529	26
27	2.5315671	2.8833686	3.2820096	3.7334563	4.2444010	4.8223459	6.2138676	27
28	2.6201720	2.9987033	3.4297000	3.9201291	4.4778431	5.1116867	6.6488384	28
29	2.7118780	3.1186515	3.5840365	4.1161356	4.7241244	5.4183879	7.1142571	29
30	2.8067937	3.2433975	3.7453181	4.3219424	4.9839513	5.7434912	7.6122550	30
31	2.9050315	3.3731334	3.9138575	4.5380395	5.2580686	6.0881006	8.1451129	31
32	3.0067076	3.5080588	4.0899810	4.7649415	5.5472624	6.4533867	8.7152708	32
33	3.1119424	3.6483811	4.2740302	5.0031885	5.8523618	6.8405899	9.3253398	33
34	3.2208603	3.7943163	4.4663615	5.2533480	6.1742417	7.2510253	9.9781135	34
35	3.3335905	3.9460890	4.6673478	5.5160154	6.5138250	7.6860868	10.6765815	35
36	3.4502661	4.1039326	4.8773785	5.7918161	6.8720854	8.1472520	11.4239422	36
37	3.5710254	4.2680899	5.0968605	6.0814069	7.2500501	8.6360871	12.2236181	37
38	3.6960113	4.4388135	5.3262192	6.3854773	7.6488028	9.1542524	13.0792714	38
39	3.8253717	4.6163660	5.5658991	6.7047512	8.0694870	9.7035075	13.9948204	39
40	3.9592597	4.8010206	5.8163645	7.0399887	8.5133088	10.2857179	14.9744578	40
41	4.0978338	4.9930615	6.0781009	7.3919882	8.9815408	10.9028610	16.0226699	41
42	4.2412580	5.1927839	6.3516155	7.7615876	9.4755255	11.5570327	17.1442568	42
43	4.3897020	5.4004953	6.6374382	8.1496669	9.9966794	12.2504546	18.3443548	43
44	4.5433416	5.6165151	6.9361229	8.5571503	10.5464968	12.9854819	19.6284596	44
45	4.7023586	5.8411757	7.2482484	8.9850078	11.1265541	13.7646108	21.0024518	45
46	4.8669411	6.0748227	7.5744196	9.4342582	11.7385146	14.5904875	22.4726234	46
47	5.0372840	6.3178156	7.9152685	9.9059711	12.3841329	15.4659167	24.0457070	47
48	5.2135890	6.5705282	8.2714556	10.4012697	13.0652602	16.3938717	25.7289065	48
49	5.3960646	6.8333494	8.6436711	10.9213331	13.7838495	17.3775040	27.5299300	49
50	5.5849269	7.1066834	9.0326363	11.4673998	14.5419612	18.4201543	29.4570251	50
51	5.7803993	7.3909507	9.4391049	12.0407698	15.3417691	19.5253635	31.5190168	51
52	5.9827133	7.6865887	9.8638646	12.6428083	16.1855664	20.6968853	33.7253480	52
53	6.1921082	7.9940523	10.3077385	13.2749487	17.0757725	21.9386985	36.0861224	53
54	6.4088320	8.3138144	10.7715868	13.9386961	18.0149400	23.2550204	38.6121509	54
55	6.6331411	8.6463669	11.2563082	14.6356309	19.0057617	24.6503216	41.3150015	55
56	6.8653011	8.9922216	11.7628420	15.3674125	20.0510786	26.1293409	44.2070516	56
57	7.1055866	9.3519105	12.2921699	16.1357831	21.1538879	27.6971013	47.3015452	57
58	7.3542822	9.7259869	12.8453176	16.9425722	22.3173518	29.3589274	50.6126534	58
59	7.6116820	10.1150264	13.4233569	17.7897009	23.5448061	31.1204631	54.1555391	59
60	7.8780909	10.5196274	14.0274079	18.6971859	24.8397705	32.9876909	57.9464268	60

TABLE 32.—*The accumulation of an annuity of 1 per annum at the end of n years.*

$$s_{\overline{n|}}=\frac{(1+i)^n-1}{i}.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1
2	2.0150000	2.0175000	2.0200000	2.0225000	2.0250000	2.0275000	2.0300000	2
3	3.0452250	3.0528063	3.0604000	3.0680063	3.0756250	3.0832563	3.0909000	3
4	4.0909034	4.1062304	4.1216080	4.1370364	4.1525156	4.1680458	4.1836270	4
5	5.1522669	5.1780894	5.2040402	5.2301197	5.2563285	5.2826671	5.3091358	5
6	6.2295509	6.2687060	6.3081210	6.3477974	6.3877367	6.4279404	6.4684099	6
7	7.3229942	7.3784083	7.4342834	7.4906228	7.5474302	7.6047088	7.6624622	7
8	8.4328391	8.5075305	8.5829691	8.6591619	8.7361159	8.8138383	8.8923361	8
9	9.5593317	9.6564122	9.7546284	9.8539930	9.9545188	10.0562188	10.1591061	9
10	10.7027217	10.8253995	10.9497210	11.0757078	11.2033818	11.3327648	11.4638793	10
11	11.8632625	12.0148439	12.1687154	12.3249113	12.4834663	12.6444159	12.8077957	11
12	13.0412114	13.2251037	13.4120897	13.6022218	13.7955530	13.9921373	14.1920296	12
13	14.2368296	14.4565430	14.6803315	14.9082718	15.1404418	15.3769211	15.6177905	13
14	15.4503821	15.7095325	15.9739382	16.2437079	16.5189528	16.7997864	17.0863242	14
15	16.6821378	16.9844494	17.2934169	17.6091913	17.9319267	18.2617805	18.5989139	15
16	17.9323698	18.2816772	18.6392853	19.0053981	19.3802248	19.7639795	20.1568813	16
17	19.2013554	19.6016066	20.0120710	20.4330196	20.8647305	21.3074889	21.7615877	17
18	20.4893757	20.9446347	21.4123124	21.8927625	22.3863487	22.8934449	23.4144354	18
19	21.7967164	22.3111658	22.8405586	23.3853497	23.9460074	24.5230146	25.1168684	19
20	23.1236671	23.7016112	24.2973698	24.9115200	25.5446576	26.1973975	26.8703745	20
21	24.4705221	25.1163894	25.7833172	26.4720292	27.1832741	27.9178259	28.6764857	21
22	25.8375799	26.5559262	27.2989835	28.0676499	28.8628559	29.6855662	30.5367803	22
23	27.2251436	28.0206549	28.8449632	29.6991720	30.5844273	31.5019192	32.4528837	23
24	28.6335208	29.5110164	30.4218625	31.3674034	32.3490380	33.3682220	34.4264702	24
25	30.0630236	31.0274592	32.0302997	33.0731700	34.1577639	35.2858481	36.4592643	25
26	31.5139690	32.5704397	33.6709057	34.8173163	36.0117080	37.2562089	38.5530423	26
27	32.9866785	34.1404224	35.3443238	36.6007059	37.9120007	39.2807547	40.7096335	27
28	34.4814787	35.7378798	37.0512103	38.4242218	39.8598008	41.3609754	42.9309225	28
29	35.9987009	37.3632927	38.7922345	40.2887668	41.8562958	43.4984022	45.2188502	29
30	37.5386814	39.0171503	40.5680792	42.1952640	43.9027032	45.6946083	47.5754157	30
31	39.1017616	40.6999504	42.3794408	44.1446575	46.0002707	47.9512100	50.0026782	31
32	40.6882880	42.4121996	44.2270296	46.1379123	48.1502775	50.2698683	52.5027585	32
33	42.2986123	44.1544131	46.1115702	48.1760153	50.3540345	52.6522897	55.0778413	33
34	43.9330915	45.9271153	48.0338016	50.2599756	52.6128853	55.1002277	57.7301765	34
35	45.5920879	47.7308398	49.9944776	52.3908251	54.9282074	57.6154839	60.4620818	35
36	47.2759692	49.5661295	51.9943672	54.5696186	57.3014126	60.1999097	63.2759443	36
37	48.9851087	51.4335368	54.0342545	56.7974351	59.7339479	62.8554072	66.1742226	37
38	50.7198854	53.3336236	56.1149396	59.0753774	62.2272966	65.5839309	69.1594493	38
39	52.4806837	55.2669621	58.2372384	61.4045733	64.7829791	68.3874890	72.2342328	39
40	54.2678939	57.2341339	60.4019832	63.7861762	67.4025535	71.2681450	75.4012597	40
41	56.0819123	59.2357312	62.6100228	66.2213652	70.0876174	74.2280190	78.6632975	41
42	57.9231410	61.2723565	64.8622233	68.7113459	72.8398078	77.2692895	82.0231965	42
43	59.7919881	63.3446228	67.1594678	71.2573512	75.6608030	80.3941950	85.4838923	43
44	61.6888679	65.4531537	69.5026571	73.8606416	78.5523231	83.6050353	89.0484091	44
45	63.6142010	67.5985839	71.8927103	76.5225061	81.5161312	86.9041738	92.7198614	45
46	65.5684140	69.7815591	74.3305645	79.2442624	84.5540344	90.2940386	96.5014572	46
47	67.5519402	72.0027364	76.8171758	82.0272583	87.6678853	93.7771246	100.3965010	47
48	69.5652193	74.2627843	79.3535193	84.8728717	90.8595824	97.3559956	104.4083960	48
49	71.6086976	76.5623830	81.9405897	87.7825113	94.1310720	101.0332854	108.5406479	49
50	73.6828280	78.9022247	84.5794015	90.7576178	97.4843488	104.8117008	112.7968673	50
51	75.7880705	81.2830136	87.2709895	93.7996642	100.9214575	108.6940226	117.1807733	51
52	77.9248915	83.7054664	90.0164093	96.9101566	104.4444940	112.6831082	121.6961965	52
53	80.0937649	86.1703120	92.8167375	100.0906351	108.0556063	116.7818937	126.3470824	53
54	82.2951714	88.6782925	95.6730722	103.3426744	111.7569965	120.9933957	131.1374949	54
55	84.5295989	91.2301626	98.5865337	106.6678846	115.5509214	125.3207141	136.0716197	55
56	86.7975429	93.8266904	101.5582643	110.0679120	119.4396944	129.7670338	141.1537683	56
57	89.0995061	96.4686575	104.5894296	113.5444400	123.4256868	134.3356272	146.3883814	57
58	91.4359987	99.1568590	107.6812182	117.0991899	127.5113289	139.0298569	151.7800328	58
59	93.8075386	101.8921041	110.8348426	120.7339217	131.6991122	143.8531780	157.3334338	59
60	96.2146517	104.6752159	114.0515394	124.4504349	135.9915900	148.8091404	163.0534368	60

TABLE 32.—*The accumulation of an annuity of 1 per annum at the end of n years*—Con.

$$s_{\overline{n|}}=\frac{(1+i)^n-1}{i}.$$

Yrs.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Yrs.
1	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1
2	2.0350000	2.0400000	2.0450000	2.0500000	2.0550000	2.0600000	2.0700000	2
3	3.1062250	3.1216000	3.1370250	3.1525000	3.1680250	3.1836000	3.2149000	3
4	4.2149429	4.2464640	4.2781911	4.3101250	4.3422664	4.3746160	4.4399430	4
5	5.3624659	5.4163226	5.4707097	5.5256313	5.5810910	5.6370930	5.7507390	5
6	6.5501522	6.6329755	6.7168917	6.8019128	6.8880510	6.9753185	7.1532907	6
7	7.7794075	7.8982945	8.0191518	8.1420085	8.2668938	8.3938377	8.6540211	7
8	9.0516868	9.2142263	9.3800136	9.5491089	9.7215730	9.8974679	10.2598026	8
9	10.3684958	10.5827953	10.8021142	11.0265643	11.2562595	11.4913160	11.9779888	9
10	11.7313932	12.0061071	12.2882094	12.5778925	12.8753538	13.1807949	13.8164480	10
11	13.1419919	13.4863514	13.8411788	14.2067872	14.5834983	14.9716426	15.7835993	11
12	14.6019616	15.0258055	15.4640318	15.9171265	16.3855907	16.8699412	17.8884513	12
13	16.1130303	16.6268377	17.1599133	17.7129829	18.2867981	18.8821377	20.1406429	13
14	17.6769864	18.2919112	18.9321094	19.5986320	20.2925720	21.0150659	22.5504879	14
15	19.2956809	20.0235876	20.7840543	21.5785636	22.4086635	23.2759699	25.1290220	15
16	20.9710297	21.8245311	22.7193367	23.6574918	24.6411400	25.6725281	27.8880536	16
17	22.7050158	23.6975124	24.7417069	25.8403664	26.9964027	28.2128798	30.8402173	17
18	24.4996913	25.6454129	26.8550837	28.1323847	29.4812048	30.9056526	33.9990325	18
19	26.3571805	27.6712294	29.0635625	30.5390039	32.1026711	33.7599917	37.3789648	19
20	28.2796818	29.7780786	31.3714228	33.0659541	34.8683180	36.7855912	40.9954923	20
21	30.2694707	31.9692017	33.7831368	35.7192518	37.7860755	39.9927267	44.8651768	21
22	32.3289022	34.2479698	36.3033780	38.5052144	40.8643097	43.3922903	49.0057392	22
23	34.4604137	36.6178886	38.9370300	41.4304751	44.1118467	46.9958277	53.4361409	23
24	36.6665282	39.0826041	41.6891963	44.5019989	47.5379983	50.8155774	58.1766708	24
25	38.9498567	41.6459083	44.5652102	47.7270988	51.1525882	54.8645120	63.2490377	25
26	41.3131017	44.3117446	47.5706446	51.1134538	54.9659805	59.1563827	68.6764704	26
27	43.7590602	47.0842144	50.7113236	54.6691265	58.9891094	63.7057657	74.4838233	27
28	46.2906273	49.9675830	53.9933332	58.4025828	63.2335105	68.5281116	80.6976909	28
29	48.9107993	52.9662863	57.4230332	62.3227119	67.7113535	73.6397983	87.3465293	29
30	51.6226773	56.0849378	61.0070697	66.4388475	72.4354780	79.0581862	94.4607863	30
31	54.4294710	59.3283353	64.7523878	70.7607899	77.4194293	84.8016774	102.0730414	31
32	57.3345025	62.7014687	68.6662452	75.2988294	82.6774[illegible]79	90.8897780	110.2181543	32
33	60.3412101	66.2095274	72.7562263	80.0637708	88.2247603	97.3431647	118.9334251	33
34	63.4531524	69.8579085	77.0302565	85.0669594	94.0771221	104.1837546	128.2587648	34
35	66.6740127	73.6522249	81.4966180	90.3203074	100.2513638	111.4347799	138.2368784	35
36	70.0076032	77.5983139	86.1639658	95.8363227	106.7651888	119.1208667	148.9134598	36
37	73.4578693	81.7022464	91.0413443	101.6281389	113.6372742	127.2681187	160.3374020	37
38	77.0288947	85.9703363	96.1382048	107.7095458	120.8873243	135.9042058	172.5610202	38
39	80.7249060	90.4091497	101.4644240	114.0950231	128.5361271	145.0584581	185.6402916	39
40	84.5502778	95.0255157	107.0303231	120.7997742	136.6056141	154.7619656	199.6351120	40
41	88.5095375	99.8265363	112.8466876	127.8397630	145.1189229	165.0476836	214.6095698	41
42	92.6073713	104.8195978	118.9247885	135.2317511	154.1004636	175.9505446	230.6322397	42
43	96.8486293	110.0123817	125.2764040	142.9933387	163.5759891	187.5075772	247.7764695	43
44	101.2383313	115.4128770	131.9138422	151.1430056	173.5726685	199.7580319	266.1208513	44
45	105.7816729	121.0293920	138.8499651	159.7001559	184.1191653	212.7435138	285.7493108	45
46	110.4840315	126.8705677	146.0982135	168.6851637	195.2457194	226.5081246	306.7517626	46
47	115.3509726	132.9453904	153.6726331	178.1194219	206.9842339	241.0986121	329.2243860	47
48	120.3882566	139.2632060	161.5879016	188.0253929	219.3683668	256.5645288	353.2700930	48
49	125.6018456	145.8337343	169.8593572	198.4266626	232.4336270	272.9584006	378.9989995	49
50	130.9979102	152.6670837	178.5030283	209.3479957	246.2174765	290.3359046	406.5289295	50
51	136.5828370	159.7737670	187.5356646	220.8153955	260.7594377	308.7560589	435.9859545	51
52	142.3632363	167.1647177	196.9747695	232.8561653	276.1012067	328.2814224	467.5049714	52
53	148.3459496	174.8513064	206.8386341	245.4989735	292.2867731	348.9783077	501.2303194	53
54	154.5380578	182.8453587	217.1463726	258.7739222	309.3625456	370.9170062	537.3164417	54
55	160.9468898	191.1591730	227.9179594	272.7126183	327.3774856	394.1720266	575.9285926	55
56	167.5800310	199.8055399	239.1742676	287.3482492	346.3832473	418.8223482	617.2435941	56
57	174.4453321	208.7977615	250.9371096	302.7156617	366.4343259	444.9516891	661.4506457	57
58	181.5509187	218.1496720	263.2292795	318.8514448	387.5882139	472.6487904	708.7521909	58
59	188.9052009	227.8756589	276.0745971	335.7940170	409.9055656	502.0077178	759.3648443	59
60	196.5168829	237.9906852	289.4979540	353.5837179	433.4503717	533.1281809	813.5203834	60

TABLE 33.—*The annual sinking fund which will accumulate to 1 at the end of n years.*

$$\frac{1}{s_n} = \frac{i}{(1+i)^n - 1}.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1
2	0.4962779	0.4956630	0.4950495	0.4944376	0.4938272	0.4932183	0.4926108	2
3	0.3283830	0.3275675	0.3267547	0.3259446	0.3251372	0.3243324	0.3235304	3
4	0.2444448	0.2435324	0.2426238	0.2417189	0.2408179	0.2399206	0.2390271	4
5	0.1940893	0.1931214	0.1921584	0.1912002	0.1902469	0.1892983	0.1883546	5
6	0.1605252	0.1595226	0.1585258	0.1575350	0.1565500	0.1555708	0.1545975	6
7	0.1365562	0.1355306	0.1345120	0.1335003	0.1324954	0.1314975	0.1305064	7
8	0.1185840	0.1175429	0.1165098	0.1154846	0.1144674	0.1134580	0.1124564	8
9	0.1046098	0.1035581	0.1025154	0.1014817	0.1004569	0.0994410	0.0984339	9
10	0.0934342	0.0923753	0.0913265	0.0902877	0.0892588	0.0882397	0.0872305	10
11	0.0842938	0.0832304	0.0821779	0.0811365	0.0801060	0.0790863	0.0780775	11
12	0.0766800	0.0756138	0.0745596	0.0735174	0.0724871	0.0714687	0.0704621	12
13	0.0702404	0.0691728	0.0681184	0.0670769	0.0660483	0.0650325	0.0640295	13
14	0.0647233	0.0636556	0.0626020	0.0615623	0.0605365	0.0595246	0.0585263	14
15	0.0599444	0.0588774	0.0578255	0.0567885	0.0557665	0.0547592	0.0537666	15
16	0.0557651	0.0546996	0.0536501	0.0526166	0.0515990	0.0505971	0.0496109	16
17	0.0520797	0.0510162	0.0499698	0.0489404	0.0479278	0.0469319	0.0459525	17
18	0.0488058	0.0477449	0.0467021	0.0456772	0.0446701	0.0436806	0.0427087	18
19	0.0458785	0.0448206	0.0437818	0.0427618	0.0417606	0.0407780	0.0398139	19
20	0.0432457	0.0421912	0.0411567	0.0401421	0.0391471	0.0381717	0.0372157	20
21	0.0408655	0.0398146	0.0387848	0.0377757	0.0367873	0.0358194	0.0348718	21
22	0.0387033	0.0376564	0.0366314	0.0356282	0.0346466	0.0336864	0.0327474	22
23	0.0367308	0.0356878	0.0346681	0.0336710	0.0326964	0.0317441	0.0308139	23
24	0.0349241	0.0338857	0.0328711	0.0318802	0.0309128	0.0299686	0.0290474	24
25	0.0332635	0.0322295	0.0312204	0.0302360	0.0292759	0.0283400	0.0274279	25
26	0.0317320	0.0307027	0.0296992	0.0287213	0.0277687	0.0268412	0.0259383	26
27	0.0303153	0.0292908	0.0282931	0.0273219	0.0263769	0.0254578	0.0245642	27
28	0.0290011	0.0279815	0.0269897	0.0260253	0.025[illegible]879	0.0241774	0.0232932	28
29	0.0277788	0.0267642	0.0257784	0.0248208	0.0238913	0.0229894	0.0221147	29
30	0.0266392	0.0256298	0.0246499	0.0236993	0.0227776	0.0218844	0.0210193	30
31	0.0255743	0.0245701	0.0235964	0.0226528	0.0217390	0.0208545	0.0199989	31
32	0.0245771	0.0235781	0.0226106	0.0216742	0.0207683	0.0198926	0.0190466	32
33	0.0236414	0.0226178	0.0216865	0.0207572	0.0198594	0.0189925	0.0181561	33
34	0.0227619	0.0217736	0.0208187	0.0198966	0.0190068	0.0181488	0.0173220	34
35	0.0219336	0.0209508	0.0200022	0.0190873	0.0182056	0.0173565	0.0165393	35
36	0.0211524	0.0201751	0.0192329	0.0183252	0.0174516	0.0166113	0.0158038	36
37	0.0204144	0.0194426	0.0185068	0.0176064	0.0167409	0.0159095	0.0151116	37
38	0.0197161	0.0187499	0.0178206	0.0169275	0.0160701	0.0152476	0.0144593	38
39	0.0190546	0.0180940	0.0171711	0.0162854	0.0154362	0.0146226	0.0138439	39
40	0.0184271	0.0174721	0.0165558	0.0156774	0.0148362	0.0140315	0.0132624	40
41	0.0178311	0.0168817	0.0159719	0.0151009	0.0142679	0.0134720	0.0127124	41
42	0.0172643	0.0163206	0.0154173	0.0145536	0.0137288	0.0129418	0.0121917	42
43	0.0167247	0.0157867	0.0148899	0.0140336	0.0132169	0.0124387	0.0116981	43
44	0.0162104	0.0152781	0.0143879	0.0135390	0.0127304	0.0119610	0.0112298	44
45	0.0157198	0.0147932	0.0139096	0.0130681	0.0122675	0.0115069	0.0107852	45
46	0.0152512	0.0143304	0.0134534	0.0126192	0.0118268	0.0110749	0.0103625	46
47	0.0148034	0.0138884	0.0130179	0.0121911	0.0114067	0.0106636	0.0099605	47
48	0.0143750	0.0134657	0.0126018	0.0117823	0.0110060	0.0102716	0.0095778	48
49	0.0139648	0.0130612	0.0122040	0.0113918	0.0106235	0.0098977	0.0092131	49
50	0.0135717	0.0126739	0.0118232	0.0110184	0.0102581	0.0095409	0.0088655	50
51	0.0131947	0.0123027	0.0114586	0.0106610	0.0099087	0.0092001	0.0085338	51
52	0.0128329	0.0119467	0.0111091	0.0103188	0.0095745	0.0088744	0.0082172	52
53	0.0124854	0.0116049	0.0107739	0.0099909	0.0092545	0.0085630	0.0079147	53
54	0.0121514	0.0112767	0.0104523	0.0096765	0.0089480	0.0082649	0.0076256	54
55	0.0118302	0.0109613	0.0101434	0.0093749	0.0086542	0.0079795	0.0073491	55
56	0.0115211	0.0106580	0.0098466	0.0090853	0.0083724	0.0077061	0.0070845	56
57	0.0112234	0.0103661	0.0095612	0.0088071	0.0081020	0.0074440	0.0068311	57
58	0.0109366	0.0100850	0.0092867	0.0085398	0.0078424	0.0071927	0.0065885	58
59	0.0106601	0.0098143	0.0090224	0.0082827	0.0075931	0.0069515	0.0063559	59
60	0.0103934	0.0095534	0.0087680	0.0080353	0.0073534	0.0067200	0.0061330	60

Table 33.—*The annual sinking fund which will accumulate to 1 at the end of n years*—Continued.

$$\frac{1}{s_{\overline{n}|}}=\frac{i}{(1+i)^n-1}.$$

Years.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Years.
1	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1
2	0.4914005	0.4901961	0.4889976	0.4878049	0.4866180	0.4854369	0.4830918	2
3	0.3219342	0.3203485	0.3187734	0.3172086	0.3156541	0.3141098	0.3110517	3
4	0.2372511	0.2354901	0.2337437	0.2320118	0.2302945	0.2285915	0.2252281	4
5	0.1864814	0.1846271	0.1827916	0.1809748	0.1791764	0.1773964	0.1738907	5
6	0.1526682	0.1507619	0.1488784	0.1470175	0.1451790	0.1433626	0.1397958	6
7	0.1285445	0.1266096	0.1247015	0.1228198	0.1209644	0.1191350	0.1155532	7
8	0.1104767	0.1085278	0.1066097	0.1047218	0.1028640	0.1010359	0.0974678	8
9	0.0964460	0.0944930	0.0925745	0.0906901	0.0888395	0.0870222	0.0834865	9
10	0.0852414	0.0832909	0.0813788	0.0795046	0.0776678	0.0758680	0.0723775	10
11	0.0760920	0.0741490	0.0722482	0.0703889	0.0685707	0.0667929	0.0633569	11
12	0.0684840	0.0665522	0.0646662	0.0628254	0.0610292	0.0592770	0.0559020	12
13	0.0620616	0.0601437	0.0582754	0.0564558	0.0546843	0.0529601	0.0496509	13
14	0.0565707	0.0546690	0.0528203	0.0510240	0.0492791	0.0475849	0.0443449	14
15	0.0518251	0.0499411	0.0481138	0.0463423	0.0446256	0.0429628	0.0397946	15
16	0.0476848	0.0458200	0.0440154	0.0422699	0.0405825	0.0389521	0.0358577	16
17	0.0440431	0.0421985	0.0404176	0.0386991	0.0370420	0.0354448	0.0324252	17
18	0.0408168	0.0389933	0.0372369	0.0355462	0.0339199	0.0323565	0.0294126	18
19	0.0379403	0.0361386	0.0344073	0.0327450	0.0311501	0.0296209	0.0267530	19
20	0.0353611	0.0335818	0.0318761	0.0302426	0.0286793	0.0271846	0.0243929	20
21	0.0330366	0.0312801	0.0296006	0.0279961	0.0264648	0.0250046	0.0222890	21
22	0.0309321	0.0291988	0.0275457	0.0259705	0.0244712	0.0230456	0.0204058	22
23	0.0290188	0.0273091	0.0256825	0.0241368	0.0226696	0.0212785	0.0187139	23
24	0.0272728	0.0255868	0.0239870	0.0224709	0.0210358	0.0196790	0.0171890	24
25	0.0256740	0.0240120	0.0224390	0.0209525	0.0195494	0.0182267	0.0158105	25
26	0.0242054	0.0225674	0.0210214	0.0195643	0.0181931	0.0169044	0.0145610	26
27	0.0228524	0.0212385	0.0197195	0.0182919	0.0169523	0.0156972	0.0134257	27
28	0.0216027	0.0200130	0.0185208	0.0171225	0.0158144	0.0145926	0.0123919	28
29	0.0204454	0.0188799	0.0174146	0.0160455	0.0147686	0.0135796	0.0114487	29
30	0.0193713	0.0178301	0.0163915	0.0150514	0.0138054	0.0126489	0.0105864	30
31	0.0183724	0.0168554	0.0154435	0.0141321	0.0129167	0.0117922	0.0097969	31
32	0.0174415	0.0159486	0.0145632	0.0132804	0.0120952	0.0110023	0.0090729	32
33	0.0165724	0.0151036	0.0137445	0.0124900	0.0113347	0.0102729	0.0084081	33
34	0.0157597	0.0143148	0.0129819	0.0117554	0.0106296	0.0095984	0.0077967	34
35	0.0149984	0.0135773	0.0122705	0.0110717	0.0099749	0.0089739	0.0072340	35
36	0.0142842	0.0128869	0.0116058	0.0104345	0.0093664	0.0083948	0.0067153	36
37	0.0136133	0.0122396	0.0109840	0.0098398	0.0087999	0.0078574	0.0062369	37
38	0.0129821	0.0116319	0.0104017	0.0092842	0.0082722	0.0073581	0.0057951	38
39	0.0123878	0.0110608	0.0098557	0.0087646	0.0077799	0.0068938	0.0053868	39
40	0.0118273	0.0105235	0.0093432	0.0082782	0.0073203	0.0064615	0.0050091	40
41	0.0112982	0.0100174	0.0088616	0.0078223	0.0068909	0.0060589	0.0046596	41
42	0.0107983	0.0095402	0.0084087	0.0073947	0.0064893	0.0056834	0.0043359	42
43	0.0103254	0.0090899	0.0079824	0.0069933	0.0061134	0.0053331	0.0040359	43
44	0.0098777	0.0086645	0.0075807	0.0066163	0.0057613	0.0050061	0.0037577	44
45	0.0094534	0.0082625	0.0072020	0.0062617	0.0054313	0.0047005	0.0034996	45
46	0.0090511	0.0078821	0.0068447	0.0059282	0.0051218	0.0044149	0.0032600	46
47	0.0086692	0.0075219	0.0065073	0.0056142	0.0048313	0.0041477	0.0030374	47
48	0.0083065	0.0071807	0.0061886	0.0053184	0.0045585	0.0038977	0.0028307	48
49	0.0079617	0.0068571	0.0058872	0.0050397	0.0043023	0.0036636	0.0026385	49
50	0.0076337	0.0065502	0.0056022	0.0047767	0.0040615	0.0034443	0.0024599	50
51	0.0073216	0.0062589	0.0053323	0.0045287	0.0038350	0.0032388	0.0022937	51
52	0.0070243	0.0059821	0.0050768	0.0042945	0.0036219	0.0030462	0.0021390	52
53	0.0067410	0.0057192	0.0048347	0.0040733	0.0034213	0.0028655	0.0019951	53
54	0.0064709	0.0054691	0.0046052	0.0038644	0.0032325	0.0026960	0.0018611	54
55	0.0062132	0.0052312	0.0043875	0.0036669	0.0030546	0.0025370	0.0017363	55
56	0.0059673	0.0050049	0.0041811	0.0034801	0.0028870	0.0023877	0.0016201	56
57	0.0057325	0.0047893	0.0039851	0.0033034	0.0027290	0.0022474	0.0015118	57
58	0.0055081	0.0045840	0.0037990	0.0031363	0.0025801	0.0021157	0.0014109	58
59	0.0052937	0.0043884	0.0036222	0.0029780	0.0024396	0.0019920	0.0013169	59
60	0.0050886	0.0042019	0.0034543	0.0028282	0.0023071	0.0018757	0.0012292	60

TABLE 34.—*The present value of 1 due in n years.*

$$v^n = (1+i)^{-n}.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	0.9852217	0.9828010	0.9803922	0.9779951	0.9756098	0.9732360	0.9708738	1
2	0.9706618	0.9658978	0.9611688	0.9564744	0.9518144	0.9471883	0.9425959	2
3	0.9563170	0.9492853	0.9423223	0.9354273	0.9285994	0.9218378	0.9151417	3
4	0.9421842	0.9329585	0.9238454	0.9148434	0.9059506	0.8971657	0.8884871	4
5	0.9282603	0.9169125	0.9057308	0.8947123	0.8838543	0.8731540	0.8626088	5
6	0.9145422	0.9011425	0.8879714	0.8750243	0.8622969	0.8497849	0.8374843	6
7	0.9010268	0.8856438	0.8705602	0.8557695	0.8412652	0.8270413	0.8130915	7
8	0.8877111	0.8704116	0.8534904	0.8369384	0.8207466	0.8049064	0.7894092	8
9	0.8745922	0.8554414	0.8367553	0.8185216	0.8007284	0.7833639	0.7664167	9
10	0.8616672	0.8407286	0.8203483	0.8005101	0.7811984	0.7623979	0.7440939	10
11	0.8489332	0.8262689	0.8042630	0.7828950	0.7621448	0.7419931	0.7224213	11
12	0.8363874	0.8120579	0.7884932	0.7656675	0.7435559	0.7221344	0.7013799	12
13	0.8240270	0.7980913	0.7730325	0.7488191	0.7254204	0.7028072	0.6809513	13
14	0.8118493	0.7843649	0.7578750	0.7323414	0.7077272	0.6839973	0.6611178	14
15	0.7998515	0.7708746	0.7430147	0.7162263	0.6904656	0.6656908	0.6418620	15
16	0.7880310	0.7576163	0.7284458	0.7004658	0.6736249	0.6478742	0.6231669	16
17	0.7763853	0.7445861	0.7141626	0.6850521	0.6571951	0.6305345	0.6050165	17
18	0.7649116	0.7317799	0.7001594	0.6699776	0.6411659	0.6136589	0.5873946	18
19	0.7536075	0.7191940	0.6864308	0.6552348	0.6255277	0.5972350	0.5702860	19
20	0.7424704	0.7068246	0.6729713	0.6408165	0.6102709	0.5812506	0.5536758	20
21	0.7314980	0.6946679	0.6597758	0.6267154	0.5953863	0.5656940	0.5375493	21
22	0.7206876	0.6827203	0.6468390	0.6129246	0.5808647	0.5505538	0.5218925	22
23	0.7100371	0.6709782	0.6341559	0.5994372	0.5666972	0.5358187	0.5066918	23
24	0.6995439	0.6594380	0.6217215	0.5862467	0.5528754	0.5214781	0.4919337	24
25	0.6892058	0.6480963	0.6095309	0.5733464	0.5393906	0.5075213	0.4776056	25
26	0.6790205	0.6369497	0.5975793	0.5607300	0.5262347	0.4939380	0.4636947	26
27	0.6689857	0.6259948	0.5858620	0.5483912	0.5133997	0.4807182	0.4501891	27
28	0.6590993	0.6152283	0.5743746	0.5363239	0.5008778	0.4678523	0.4370768	28
29	0.6493589	0.6046470	0.5631123	0.5245221	0.4886613	0.4553307	0.4243464	29
30	0.6397624	0.5942476	0.5520709	0.5129801	0.4767427	0.4431442	0.4119868	30
31	0.6303078	0.5840272	0.5412460	0.5016920	0.4651148	0.4312839	0.3999872	31
32	0.6209929	0.5739825	0.5306333	0.4906523	0.4537706	0.4197410	0.3883370	32
33	0.6118157	0.5641105	0.5202287	0.4798556	0.4427030	0.4085071	0.3770263	33
34	0.6027741	0.5544084	0.5100282	0.4692964	0.4319053	0.3975738	0.3660449	34
35	0.5938661	0.5448731	0.5000276	0.4589696	0.4213711	0.3869331	0.3553834	35
36	0.5850897	0.5355018	0.4902232	0.4488700	0.4110937	0.3765773	0.3450324	36
37	0.5764431	0.5262917	0.4806109	0.4389927	0.4010671	0.3664986	0.3349829	37
38	0.5679242	0.5172400	0.4711872	0.4293327	0.3912849	0.3566896	0.3252262	38
39	0.5595313	0.5083440	0.4619482	0.4198853	0.3817414	0.3471432	0.3157536	39
40	0.5512623	0.4996010	0.4528904	0.4106458	0.3724306	0.3378522	0.3065568	40
41	0.5431156	0.4910083	0.4440102	0.4016095	0.3633470	0.3288100	0.2976280	41
42	0.5350893	0.4825635	0.4353041	0.3927722	0.3544848	0.3200097	0.2889592	42
43	0.5271815	0.4742639	0.4267688	0.3841293	0.3458389	0.3114450	0.2805429	43
44	0.5193907	0.4661070	0.4184007	0.3756765	0.3374038	0.3031094	0.2723718	44
45	0.5117149	0.4580904	0.4101968	0.3674098	0.3291744	0.2949970	0.2644386	45
46	0.5041527	0.4502117	0.4021537	0.3593250	0.3211458	0.2871017	0.2567365	46
47	0.4967021	0.4424685	0.3942684	0.3514181	0.3133129	0.2794177	0.2492588	47
48	0.4893617	0.4348585	0.3865376	0.3436852	0.3056712	0.2719394	0.2419988	48
49	0.4821298	0.4273793	0.3789584	0.3361224	0.2982158	0.2646612	0.2349503	49
50	0.4750047	0.4200288	0.3715279	0.3287261	0.2909422	0.2575778	0.2281071	50
51	0.4679849	0.4128048	0.3642430	0.3214925	0.2838461	0.2506840	0.2214632	51
52	0.4610689	0.4057049	0.3571010	0.3144181	0.2769230	0.2439747	0.2150128	52
53	0.4542551	0.3987272	0.3500990	0.3074994	0.2701688	0.2374450	0.2087503	53
54	0.4475419	0.3918695	0.3432343	0.3007329	0.2635793	0.2310900	0.2026702	54
55	0.4409280	0.3851297	0.3365043	0.2941153	0.2571505	0.2249051	0.1967672	55
56	0.4344118	0.3785059	0.3299061	0.2876433	0.2508786	0.2188858	0.1910361	56
57	0.4279919	0.3719959	0.3234374	0.2813137	0.2447596	0.2130275	0.1854719	57
58	0.4216669	0.3655980	0.3170955	0.2751235	0.2387898	0.2073260	0.1800698	58
59	0.4154354	0.3593100	0.3108779	0.2690694	0.2329657	0.2017772	0.1748251	59
60	0.4092960	0.3531303	0.3047823	0.2631486	0.2272836	0.1963768	0.1697331	60

TABLE 34.—*The present value of 1 due in n years*—Continued.

$$v^n=(1+i)^{-n}.$$

Years.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Years.
1	0.9661836	0.9615385	0.9569378	0.9523810	0.9478673	0.9433962	0.9345794	1
2	0.9335107	0.9245562	0.9157300	0.9070295	0.8984524	0.8899964	0.8734387	2
3	0.9019427	0.8889964	0.8762966	0.8638376	0.8516137	0.8396193	0.8162979	3
4	0.8714422	0.8548042	0.8385613	0.8227025	0.8072167	0.7920937	0.7628952	4
5	0.8419732	0.8219271	0.8024511	0.7835262	0.7651344	0.7472582	0.7129862	5
6	0.8135006	0.7903145	0.7678957	0.7462154	0.7252458	0.7049605	0.6663422	6
7	0.7859910	0.7599178	0.7348285	0.7106813	0.6874368	0.6650571	0.6227497	7
8	0.7594116	0.7306902	0.7031851	0.6768394	0.6515989	0.6274124	0.5820091	8
9	0.7337310	0.7025867	0.6729044	0.6446089	0.6176293	0.5918985	0.5439337	9
10	0.7089188	0.6755642	0.6439277	0.6139133	0.5854306	0.5583948	0.5083493	10
11	0.6849457	0.6495809	0.6161987	0.5846793	0.5549105	0.5267875	0.4750928	11
12	0.6617833	0.6245971	0.5896639	0.5568374	0.5259815	0.4969694	0.4440120	12
13	0.6394042	0.6005741	0.5642716	0.5303214	0.4985607	0.4688390	0.4149645	13
14	0.6177818	0.5774751	0.5399729	0.5050680	0.4725694	0.4423010	0.3878172	14
15	0.5968906	0.5552645	0.5167204	0.4810171	0.4479331	0.4172651	0.3624460	15
16	0.5767059	0.5339082	0.4944693	0.4581115	0.4245811	0.3936463	0.3387346	16
17	0.5572038	0.5133733	0.4731764	0.4362967	0.4024465	0.3713644	0.3165744	17
18	0.5383611	0.4936281	0.4528004	0.4155207	0.3814659	0.3503438	0.2958639	18
19	0.5201557	0.4746424	0.4333018	0.3957340	0.3615791	0.3305130	0.2765083	19
20	0.5025659	0.4563870	0.4146429	0.3768895	0.3427290	0.3118047	0.2584190	20
21	0.4855709	0.4388336	0.3967874	0.3589424	0.3248616	0.2941554	0.2415131	21
22	0.4691506	0.4219554	0.3797009	0.3418499	0.3079257	0.2775051	0.2257132	22
23	0.4532856	0.4057263	0.3633501	0.3255713	0.2918727	0.2617973	0.2109469	23
24	0.4379571	0.3901215	0.3477035	0.3100679	0.2766566	0.2469786	0.1971466	24
25	0.4231470	0.3751168	0.3327306	0.2953028	0.2622337	0.2329986	0.1842492	25
26	0.4088377	0.3606892	0.3184025	0.2812407	0.2485628	0.2198100	0.1721955	26
27	0.3950122	0.3468166	0.3046914	0.2678483	0.2356045	0.2073680	0.1609304	27
28	0.3816543	0.3334775	0.2915707	0.2550936	0.2233218	0.1956301	0.1504022	28
29	0.3687482	0.3206514	0.2790150	0.2429463	0.2116794	0.1845567	0.1405628	29
30	0.3562784	0.3083187	0.2670000	0.2313775	0.2006440	0.1741101	0.1313671	30
31	0.3442304	0.2964603	0.2555024	0.2203595	0.1901839	0.1642548	0.1227730	31
32	0.3325897	0.2850579	0.2444999	0.2098662	0.1802691	0.1549574	0.1147411	32
33	0.3213427	0.2740942	0.2339712	0.1998725	0.1708712	0.1461862	0.1072347	33
34	0.3104761	0.2635521	0.2238959	0.1903548	0.1619632	0.1379115	0.1002193	34
35	0.2999769	0.2534155	0.2142544	0.1812903	0.1535196	0.1301052	0.0936629	35
36	0.2898327	0.2436687	0.2050282	0.1726574	0.1455162	0.1227408	0.0875355	36
37	0.2800316	0.2342969	0.1961992	0.1644356	0.1379301	0.1157932	0.0818088	37
38	0.2705619	0.2252854	0.1877504	0.1566054	0.1307394	0.1092389	0.0764569	38
39	0.2614125	0.2166206	0.1796655	0.1491480	0.1239236	0.1030555	0.0714550	39
40	0.2525725	0.2082890	0.1719287	0.1420457	0.1174631	0.0972222	0.0667804	40
41	0.2440314	0.2002779	0.1645251	0.1352816	0.1113395	0.0917191	0.0624116	41
42	0.2357791	0.1925749	0.1574403	0.1288396	0.1055350	0.0865274	0.0583286	42
43	0.2278059	0.1851682	0.1506605	0.1227044	0.1000332	0.0816296	0.0545127	43
44	0.2201023	0.1780464	0.1441728	0.1168613	0.0948182	0.0770091	0.0509464	44
45	0.2126592	0.1711984	0.1379644	0.1112965	0.0898751	0.0726501	0.0476135	45
46	0.2054679	0.1646139	0.1320233	0.1059967	0.0851897	0.0685378	0.0444986	46
47	0.1985197	0.1582826	0.1263381	0.1009492	0.0807485	0.0646583	0.0415875	47
48	0.1918065	0.1521948	0.1208977	0.0961421	0.0765389	0.0609984	0.0388668	48
49	0.1853202	0.1463411	0.1156916	0.0915639	0.0725487	0.0575457	0.0363241	49
50	0.1790534	0.1407126	0.1107097	0.0872037	0.0687665	0.0542884	0.0339478	50
51	0.1729984	0.1353006	0.1059423	0.0830512	0.0651815	0.0512154	0.0317269	51
52	0.1671482	0.1300967	0.1013801	0.0790964	0.0617834	0.0483165	0.0296513	52
53	0.1614959	0.1250930	0.0970145	0.0753299	0.0585625	0.0455816	0.0277115	53
54	0.1560347	0.1202817	0.0928368	0.0717427	0.0555095	0.0430015	0.0258986	54
55	0.1507581	0.1156555	0.0888391	0.0683264	0.0526156	0.0405674	0.0242043	55
56	0.1456600	0.1112072	0.0850135	0.0650728	0.0498726	0.0382712	0.0226208	56
57	0.1407343	0.1069300	0.0813526	0.0619741	0.0472726	0.0361049	0.0211410	57
58	0.1359752	0.1028173	0.0778494	0.0590229	0.0448082	0.0340612	0.0197579	58
59	0.1313770	0.0988628	0.0744970	0.0562123	0.0424722	0.0321332	0.0184653	59
60	0.1269343	0.0950604	0.0712890	0.0535355	0.0402580	0.0303143	0.0172573	60

TABLE 35.—*The present value of an annuity of 1 for n years.*

$$a_{\overline{n}|} = \frac{1-v^n}{i}.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	0. 9852217	0. 9828010	0. 9803922	0. 9779951	0. 9756098	0. 9732360	0. 9708738	1
2	1. 9558834	1. 9486988	1. 9415609	1. 9344696	1. 9274242	1. 9204243	1. 9134697	2
3	2. 9122004	2. 8979840	2. 8838833	2. 8698969	2. 8560236	2. 8422621	2. 8286114	3
4	3. 8543847	3. 8309425	3. 8077287	3. 7847402	3. 7619742	3. 7394279	3. 7170984	4
5	4. 7826450	4. 7478551	4. 7134595	4. 6794525	4. 6458285	4. 6125819	4. 5797072	5
6	5. 6971872	5. 6489976	5. 6014309	5. 5544768	5. 5081254	5. 4623668	5. 4171914	6
7	6. 5982140	6. 5346414	6. 4719911	6. 4102463	6. 3493906	6. 2894081	6. 2302830	7
8	7. 4859251	7. 4050530	7. 3254814	7. 2471846	7. 1701372	7. 0943144	7. 0196922	8
9	8. 3605173	8. 2604943	8. 1622367	8. 0657062	7. 9708655	7. 8776783	7. 7861089	9
10	9. 2221846	9. 1012229	8. 9825850	8. 8662164	8. 7520639	8. 6400762	8. 5302028	10
11	10. 0711178	9. 9274918	9. 7868481	9. 6491113	9. 5142087	9. 3820693	9. 2526241	11
12	10. 9075052	10. 7395497	10. 5753412	10. 4147788	10. 2577646	10. 1042037	9. 9540040	12
13	11. 7315322	11. 5376410	11. 3483738	11. 1635979	10. 9831850	10. 8070109	10. 6349553	13
14	12. 5433815	12. 3220059	12. 1062488	11. 8959392	11. 6909122	11. 4910081	11. 2960731	14
15	13. 3432330	13. 0928805	12. 8492635	12. 6121655	12. 3813777	12. 1566989	11. 9379351	15
16	14. 1312641	13. 8504968	13. 5777093	13. 3126313	13. 0550027	12. 8045732	12. 5611020	16
17	14. 9076493	14. 5950828	14. 2918719	13. 9976834	13. 7121977	13. 4351077	13. 1661185	17
18	15. 6725609	15. 3268627	14. 9920313	14. 6676611	14. 3533636	14. 0487666	13. 7535131	18
19	16. 4261684	16. 0460567	15. 6784620	15. 3228959	14. 9788913	14. 6460016	14. 3237991	19
20	17. 1686388	16. 7528813	16. 3514333	15. 9637124	15. 5891623	15. 2272521	14. 8774749	20
21	17. 9001367	17. 4475492	17. 0112092	16. 5904278	16. 1845486	15. 7929461	15. 4150241	21
22	18. 6208244	18. 1302695	17. 6580482	17. 2033523	16. 7654132	16. 3434999	15. 9369166	22
23	19. 3308615	18. 8012476	18. 2922041	17. 8027896	17. 3321105	16. 8793186	16. 4436084	23
24	20. 0304054	19. 4606857	18. 9139256	18. 3890362	17. 8849858	17. 4007967	16. 9355421	24
25	20. 7196112	20. 1087820	19. 5234565	18. 9623826	18. 4243764	17. 9083180	17. 4131477	25
26	21. 3986317	20. 7457317	20. 1210358	19. 5231126	18. 9506111	18. 4022559	17. 8768424	26
27	22. 0676175	21. 3717264	20. 7068978	20. 0715038	19. 4640109	18. 8829741	18. 3270315	27
28	22. 7267167	21. 9869547	21. 2812724	20. 6078276	19. 9648887	19. 3508264	18. 7641082	28
29	23. 3760756	22. 5916017	21. 8443847	21. 1323498	20. 4535499	19. 8061571	19. 1884546	29
30	24. 0158380	23. 1858493	22. 3964556	21. 6453299	20. 9302926	20. 2493013	19. 6004414	30
31	24. 6461458	23. 7698765	22. 9377015	22. 1470219	21. 3954074	20. 6805852	20. 0004285	31
32	25. 2671387	24. 3438590	23. 4683348	22. 6376742	21. 8491780	21. 1003262	20. 3887655	32
33	25. 8789544	24. 9079695	23. 9885636	23. 1175298	22. 2918809	21. 5088333	20. 7657918	33
34	26. 4817285	25. 4623779	24. 4985917	23. 5868262	22. 7237863	21. 9064071	21. 1318367	34
35	27. 0755946	26. 0072510	24. 9986193	24. 0457958	23. 1451573	22. 2933403	21. 4872201	35
36	27. 6606843	26. 5427528	25. 4888425	24. 4946658	23. 5562511	22. 6699175	21. 8322525	36
37	28. 2371274	27. 0690446	25. 9694534	24. 9336585	23. 9573181	23. 0364161	22. 1672354	37
38	28. 8050516	27. 5862846	26. 4406406	25. 3629912	24. 3486030	23. 3931057	22. 4924616	38
39	29. 3645829	28. 0946286	26. 9025888	25. 7828765	24. 7303444	23. 7402488	22. 8082151	39
40	29. 9158452	28. 5942296	27. 3554792	26. 1935222	25. 1027751	24. 0781011	23. 1147720	40
41	30. 4589608	29. 0852379	27. 7994895	26. 5951317	25. 4661220	24. 4069110	23. 4124000	41
42	30. 9940500	29. 5678014	28. 2347936	26. 9879039	25. 8206068	24. 7269207	23. 7013592	42
43	31. 5212316	30. 0420652	28. 6615623	27. 3720332	26. 1664457	25. 0383656	23. 9819021	43
44	32. 0406222	30. 5081722	29. 0799631	27. 7477097	26. 5038495	25. 3414751	24. 2542739	44
45	32. 5523372	30. 9662626	29. 4901599	28. 1151195	26. 8330239	25. 6364721	24. 5187125	45
46	33. 0564898	31. 4164743	29. 8923136	28. 4744445	27. 1541696	25. 9235738	24. 7754491	46
47	33. 5531920	31. 8589428	30. 2865820	28. 8258626	27. 4674826	26. 2029915	25. 0247078	47
48	34. 0425537	32. 2938013	30. 6731196	29. 1695478	27. 7731537	26. 4749309	25. 2667066	48
49	34. 5246834	32. 7211806	31. 0520780	29. 5056702	28. 0713695	26. 7395922	25. 5016569	49
50	34. 9996881	33. 1412095	31. 4236059	29. 8343963	28. 3623117	26. 9971700	25. 7297640	50
51	35. 4676730	33. 5540142	31. 7878489	30. 1558888	28. 6461577	27. 2478540	25. 9512272	51
52	35. 9287419	33. 9597191	32. 1449499	30. 4703069	28. 9230807	27. 4918287	26. 1662400	52
53	36. 3829969	34. 3584463	32. 4950489	30. 7778062	29. 1932495	27. 7292737	26. 3749903	53
54	36. 8305388	34. 7503158	32. 8382833	31. 0785391	29. 4568288	27. 9603637	26. 5776605	54
55	37. 2714668	35. 1354455	33. 1747875	31. 3726544	29. 7139793	28. 1852688	26. 7744276	55
56	37. 7058786	35. 5139514	33. 5046937	31. 6602977	29. 9648578	28. 4041545	26. 9654637	56
57	38. 1338706	35. 8859473	33. 8281310	31. 9416114	30. 2096174	28. 6171820	27. 1509357	57
58	38. 5555375	36. 2515452	34. 1452265	32. 2167349	30. 4484072	28. 8245081	27. 3310055	58
59	38. 9709729	36. 6108553	34. 4561044	32. 4858043	30. 6813729	29. 0262852	27. 5058306	59
60	39. 3802689	36. 9639855	34. 7608867	32. 7489529	30. 9086565	29. 2226620	27. 6755637	60

TABLE 35.—*The present value of an annuity of 1 for n years*—Continued.

$$a_{\overline{n}|}=\frac{1-v^n}{i}.$$

Years.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Years.
1	0.9661836	0.9615385	0.9569378	0.9523810	0.9478673	0.9433962	0.9345794	1
2	1.8996943	1.8860947	1.8726678	1.8594104	1.8463197	1.8333927	1.8080182	2
3	2.8016370	2.7750910	2.7489644	2.7232480	2.6979334	2.6730120	2.6243160	3
4	3.6730792	3.6298952	3.5875257	3.5459505	3.5051501	3.4651056	3.3872113	4
5	4.5150524	4.4518223	4.3899767	4.3294767	4.2702845	4.2123638	4.1001974	5
6	5.3285530	5.2421369	5.1578725	5.07569 3	4.9955303	4.9173243	4.7665397	6
7	6.1145440	6.0020547	5.8927009	5.7863731	5.6829671	5.5823814	5.3892894	7
8	6.8739555	6.7327449	6.5958861	6.4632128	6.3345660	6.2097938	5.9712985	8
9	7.6076865	7.4353316	7.2687905	7.1078217	6.9521953	6.8016923	6.5152323	9
10	8.3166053	8.1108958	7.9127182	7.7217349	7.5376258	7.3600871	7.0235816	10
11	9.0015510	8.7604767	8.5289169	8.3064142	8.0925363	7.8868746	7.4986744	11
12	9.6633343	9.3850738	9.1185808	8.8632516	8.6185179	8.3838439	7.9426863	12
13	10.3027385	9.9856479	9.6828524	9.3935730	9.1170785	8.8526830	8.3576508	13
14	10.9205203	10.5631229	10.2228253	9.8986409	9.5896479	9.2949839	8.7454680	14
15	11.5174109	11.1183874	10.7395457	10.3796580	10.0375809	9.7122490	9.1079140	15
16	12.0941168	11.6522956	11.2340151	10.8377696	10.4621620	10.1058953	9.4466486	16
17	12.6513206	12.1656689	11.7071914	11.2740663	10.8646086	10.4772597	9.7632230	17
18	13.1896817	12.6592970	12.1599918	11.6895869	11.2460745	10.8276035	10.0590869	18
19	13.7098374	13.1339394	12.5932936	12.0853209	11.6076535	11.1581165	10.3355953	19
20	14.2124033	13.5903263	13.0079365	12.4622103	11.9503825	11.4699212	10.5940143	20
21	14.6979742	14.0291600	13.4047239	12.8211527	12.2752441	11.7640766	10.8355273	21
22	15.1671248	14.4511153	13.7844248	13.1630026	12.5831697	12.0415817	11.0612405	22
23	15.6204105	14.8568417	14.1477749	13.4885739	12.8750424	12.3033790	11.2721874	23
24	16.0583676	15.2469631	14.4954784	13.7986418	13.1516990	12.5503575	11.4693340	24
25	16.4815146	15.6220799	14.8282090	14.0939446	13.4139327	12.7833562	11.6535832	25
26	16.8903523	15.9827692	15.1466115	14.3751853	13.6624954	13.0031662	11.8257787	26
27	17.2853645	16.3295858	15.4513028	14.6430336	13.8980999	13.2105341	11.9867091	27
28	17.6670189	16.6630632	15.7428735	14.8981273	14.1214217	13.4061643	12.1371113	28
29	18.0357670	16.9837146	16.0218885	15.1410736	14.3331012	13.5907210	12.2776741	29
30	18.3920454	17.2920333	16.2888885	15.3724510	14.5337452	13.7648312	12.4090412	30
31	18.7362758	17.5884936	16.5443910	15.5928105	14.7239291	13.9290860	12.5318142	31
32	19.0688655	17.8735515	16.7888909	15.8026767	14.9041982	14.0840434	12.6465553	32
33	19.3902082	18.1476457	17.0228621	16.0025492	15.0750694	14.2302296	12.7537900	33
34	19.7006842	18.4111978	17.2467580	16.1929040	15.2370326	14.3681411	12.8540094	34
35	20.0006611	18.6646132	17.4610124	16.3741943	15.3905522	14.4982464	12.9476723	35
36	20.2904938	18.9082820	17.6660406	16.5468517	15.5360684	14.6209871	13.0352078	36
37	20.5705254	19.1425788	17.8622398	16.7112873	15.6739985	14.7367803	13.1170166	37
38	20.8410874	19.3678642	18.0499902	16.8678927	15.8047379	14.8460192	13.1934735	38
39	21.1024999	19.5844848	18.2296557	17.0170407	15.9286615	14.9490747	13.2649285	39
40	21.3550723	19.7927739	18.4015844	17.1590864	16.0461247	15.0462969	13.3317089	40
41	21.5991037	19.9930518	18.5661095	17.2943680	16.1574642	15.1380159	13.3941204	41
42	21.8348828	20.1856267	18.7235498	17.4232076	16.2629992	15.2245433	13.4524490	42
43	22.0626887	20.3707949	18.8742103	17.5459120	16.3630324	15.3061729	13.5069617	43
44	22.2827910	20.5488413	19.0183831	17.6627733	16.4578506	15.3831820	13.5579081	44
45	22.4954503	20.7200397	19.1563474	17.7740698	16.5477257	15.4558321	13.6055216	45
46	22.7009181	20.8846536	19.2883707	17.8800665	16.6329154	15.5243699	13.6500202	46
47	22.8994378	21.0429361	19.4147088	17.9810157	16.7136639	15.5890282	13.6916077	47
48	23.0912443	21.1951309	19.5356065	18.0771578	16.7902027	15.6500266	13.7304744	48
49	23.2765645	21.3414720	19.6512981	18.1687217	16.8627514	15.7075723	13.7667986	49
50	23.4556179	21.4821846	19.7620078	18.2559255	16.9315179	15.7618606	13.8007463	50
51	23.6286163	21.6174852	19.8679500	18.3389766	16.9966994	15.8130761	13.8324732	51
52	23.7957645	21.7475819	19.9693302	18.4180730	17.0584829	15.8613925	13.8621245	52
53	23.9572604	21.8726749	20.0663447	18.4934028	17.1170454	15.9069741	13.8898359	53
54	24.1132951	21.9929567	20.1591815	18.5651456	17.1725549	15.9499755	13.9157345	54
55	24.2640532	22.1086122	20.2480206	18.6334720	17.2251705	15.9905430	13.9399388	55
56	24.4097133	22.2198194	20.3330340	18.6985447	17.2750431	16.0288141	13.9625596	56
57	24.5504476	22.3267494	20.4143866	18.7605188	17.3223158	16.0649190	13.9837006	57
58	24.6864228	22.4295668	20.4922360	18.8195417	17.3671239	16.0989802	14.0034585	58
59	24.8177998	22.5284296	20.5667330	18.8757540	17.4095961	16.1311134	14.0219238	59
60	24.9447341	22.6234900	20.6380220	18.9292895	17.4498542	16.1614277	14.0391812	60

TABLE 36.—*The annuity for n years which 1 will buy or the annuity needed to discharge a debt of 1 in n years with interest.*

$$\frac{1}{a_{\overline{n}|}}=\frac{i}{1-v^n}.$$

Years.	1½%.	1¾%.	2%.	2¼%.	2½%.	2¾%.	3%.	Years.
1	1.0150000	1.0175000	1.0200000	1.0225000	1.0250000	1.0275000	1.0300000	1
2	0.5112779	0.5131630	0.5150495	0.5169376	0.5188272	0.5207183	0.5226108	2
3	0.3433830	0.3450675	0.3467547	0.3484446	0.3501372	0.3518324	0.3535304	3
4	0.2594448	0.2610324	0.2626238	0.2642189	0.2658179	0.2674206	0.2690271	4
5	0.2090893	0.2106214	0.2121584	0.2137002	0.2152469	0.2167983	0.2183546	5
6	0.1755252	0.1770226	0.1785258	0.1800350	0.1815500	0.1830708	0.1845975	6
7	0.1515562	0.1530306	0.1545120	0.1560003	0.1574954	0.1589975	0.1605064	7
8	0.1335840	0.1350429	0.1365098	0.1379846	0.1394674	0.1409580	0.1424564	8
9	0.1196098	0.1210581	0.1225154	0.1239817	0.1254569	0.1269410	0.1284339	9
10	0.1084342	0.1098754	0.1113265	0.1127877	0.1142588	0.1157397	0.1172305	10
11	0.0992938	0.1007304	0.1021779	0.1036365	0.1051060	0.1065863	0.1080775	11
12	0.0916800	0.0931138	0.0945596	0.0960174	0.0974871	0.0989687	0.1004621	12
13	0.0852404	0.0866728	0.0881184	0.0895769	0.0910483	0.0925325	0.0940295	13
14	0.0797233	0.0811556	0.0826020	0.0840623	0.0855365	0.0870246	0.0885263	14
15	0.0749444	0.0763774	0.0778255	0.0792885	0.0807665	0.0822592	0.0837666	15
16	0.0707651	0.0721996	0.0736501	0.0751166	0.0765990	0.0780971	0.0796109	16
17	0.0670797	0.0685162	0.0699698	0.0714404	0.0729278	0.0744319	0.0759525	17
18	0.0638058	0.0652449	0.0667021	0.0681772	0.0696701	0.0711806	0.0727087	18
19	0.0608785	0.0623206	0.0637818	0.0652618	0.0667606	0.0682780	0.0698139	19
20	0.0582457	0.0596912	0.0611567	0.0626421	0.0641471	0.0656717	0.0672157	20
21	0.0558655	0.0573146	0.0587848	0.0602757	0.0617873	0.0633194	0.0648718	21
22	0.0537033	0.0551564	0.0566314	0.0581282	0.0596466	0.0611864	0.0627474	22
23	0.0517308	0.0531880	0.0546681	0.0561710	0.0576964	0.0592441	0.0608139	23
24	0.0499241	0.0513857	0.0528711	0.0543802	0.0559128	0.0574686	0.0590474	24
25	0.0482635	0.0497295	0.0512204	0.0527360	0.0542759	0.0558400	0.0574279	25
26	0.0467320	0.0482027	0.0496992	0.0512213	0.0527688	0.0543412	0.0559383	26
27	0.0453153	0.0467908	0.0482931	0.0498219	0.0513769	0.0529578	0.0545642	27
28	0.0440011	0.0454815	0.0469897	0.0485253	0.0500879	0.0516774	0.0532932	28
29	0.0427788	0.0442642	0.0457784	0.0473208	0.0488913	0.0504894	0.0521147	29
30	0.0416392	0.0431298	0.0446499	0.0461993	0.0477776	0.0493844	0.0510193	30
31	0.0405743	0.0420701	0.0435963	0.0451528	0.0467390	0.0483545	0.0499989	31
32	0.0395771	0.0410781	0.0426106	0.0441742	0.0457683	0.0473926	0.0490466	32
33	0.0386414	0.0401478	0.0416865	0.0432572	0.0448594	0.0464925	0.0481561	33
34	0.0377619	0.0392736	0.0408187	0.0423966	0.0440068	0.0456488	0.0473220	34
35	0.0369336	0.0384508	0.0400022	0.0415873	0.0432056	0.0448565	0.0465393	35
36	0.0361524	0.0376751	0.0392329	0.0408252	0.0424516	0.0441113	0.0458038	36
37	0.0354144	0.0369426	0.0385068	0.0401064	0.0417409	0.0434095	0.0451116	37
38	0.0347161	0.0362499	0.0378206	0.0394275	0.0410701	0.0427476	0.0444593	38
39	0.0340546	0.0355940	0.0371711	0.0387854	0.0404362	0.0421226	0.0438439	39
40	0.0334271	0.0349721	0.0365558	0.0381774	0.0398362	0.0415315	0.0432624	40
41	0.0328311	0.0343817	0.0359719	0.0376009	0.0392679	0.0409720	0.0427124	41
42	0.0322643	0.0338206	0.0354173	0.0370536	0.0387288	0.0404418	0.0421917	42
43	0.0317247	0.0332867	0.0348899	0.0365336	0.0382169	0.0399387	0.0416981	43
44	0.0312104	0.0327781	0.0343879	0.0360390	0.0377304	0.0394610	0.0412299	44
45	0.0307198	0.0322932	0.0339096	0.0355681	0.0372675	0.0390069	0.0407852	45
46	0.0302512	0.0318304	0.0334534	0.0351192	0.0368268	0.0385749	0.0403625	46
47	0.0298034	0.0313884	0.0330179	0.0346911	0.0364067	0.0381636	0.0399605	47
48	0.0293750	0.0309657	0.0326018	0.0342823	0.0360060	0.0377716	0.0395778	48
49	0.0289648	0.0305612	0.0322040	0.0338918	0.0356235	0.0373977	0.0392131	49
50	0.0285717	0.0301739	0.0318232	0.0335184	0.0352581	0.0370409	0.0388655	50
51	0.0281947	0.0298027	0.0314586	0.0331610	0.0349087	0.0367001	0.0385338	51
52	0.0278329	0.0294466	0.0311091	0.0328188	0.0345745	0.0363744	0.0382172	52
53	0.0274854	0.0291049	0.0307739	0.0324909	0.0342545	0.0360630	0.0379147	53
54	0.0271514	0.0287767	0.0304523	0.0321765	0.0339480	0.0357649	0.0376256	54
55	0.0268302	0.0284613	0.0301434	0.0318749	0.0336542	0.0354795	0.0373491	55
56	0.0265211	0.0281580	0.0298466	0.0315853	0.0333724	0.0352061	0.0370845	56
57	0.0262234	0.0278661	0.0295612	0.0313071	0.0331020	0.0349440	0.0368311	57
58	0.0259366	0.0275850	0.0292867	0.0310398	0.0328424	0.0346927	0.0365885	58
59	0.0256601	0.0273143	0.0290224	0.0307827	0.0325931	0.0344515	0.0363559	59
60	0.0253934	0.0270534	0.0287680	0.0305353	0.0323534	0.0342200	0.0361330	60

TABLE 36.—*The annuity for n years which 1 will buy or the annuity needed to discharge a debt of 1 in n years with interest*—Continued.

$$\frac{1}{a_{\overline{n}|}}=\frac{i}{1-v^n}.$$

Years.	3½%.	4%.	4½%.	5%.	5½%.	6%.	7%.	Years.
1	1.0350000	1.0400000	1.0450000	1.0500000	1.0550000	1.0600000	1.0700000	1
2	0.5264005	0.5301961	0.5339976	0.5378049	0.5416180	0.5454369	0.5530918	2
3	0.3569342	0.3603485	0.3637734	0.3672086	0.3706541	0.3741098	0.3810517	3
4	0.2722511	0.2754901	0.2787437	0.2820118	0.2852945	0.2885915	0.2952281	4
5	0.2214814	0.2246271	0.2277916	0.2309748	0.2341764	0.2373964	0.2438907	5
6	0.1876682	0.1907619	0.1938784	0.1970175	0.2001790	0.2033626	0.2097958	6
7	0.1635445	0.1666096	0.1697015	0.1728198	0.1759644	0.1791350	0.1855532	7
8	0.1454767	0.1485278	0.1516097	0.1547218	0.1578640	0.1610359	0.1674678	8
9	0.1314460	0.1344930	0.1375745	0.1406901	0.1438395	0.1470222	0.1534865	9
10	0.1202414	0.1232909	0.1263788	0.1295046	0.1326678	0.1358680	0.1423775	10
11	0.1110920	0.1141490	0.1172482	0.1203889	0.1235707	0.1267929	0.1333569	11
12	0.1034840	0.1065522	0.1096662	0.1128254	0.1160292	0.1192770	0.1259020	12
13	0.0970616	0.1001437	0.1032754	0.1064558	0.1096843	0.1129601	0.1196509	13
14	0.0915707	0.0946690	0.0978203	0.1010240	0.1042791	0.1075849	0.1143449	14
15	0.0868251	0.0899411	0.0931138	0.0963423	0.0996256	0.1029628	0.1097946	15
16	0.0826848	0.0858200	0.0890154	0.0922699	0.0955825	0.0989521	0.1058577	16
17	0.0790431	0.0821985	0.0854176	0.0886999	0.0920420	0.0954448	0.1024252	17
18	0.0758168	0.0789933	0.0822369	0.0855462	0.0889199	0.0923565	0.0994126	18
19	0.0729403	0.0761386	0.0794073	0.0827450	0.0861501	0.0896209	0.0967530	19
20	0.0703611	0.0735818	0.0768761	0.0802426	0.0836793	0.0871846	0.0943929	20
21	0.0680366	0.0712801	0.0746006	0.0779961	0.0814648	0.0850046	0.0922890	21
22	0.0659321	0.0691988	0.0725457	0.0759705	0.0794712	0.0830456	0.0904058	22
23	0.0640188	0.0673091	0.0706825	0.0741368	0.0776696	0.0812785	0.0887139	23
24	0.0622728	0.0655868	0.0689870	0.0724709	0.0760358	0.0796790	0.0871890	24
25	0.0606740	0.0640120	0.0674390	0.0709525	0.0745494	0.0782267	0.0858105	25
26	0.0592054	0.0625674	0.0660214	0.0695643	0.0731931	0.0769044	0.0845610	26
27	0.0578524	0.0612385	0.0647195	0.0682919	0.0719523	0.0756972	0.0834257	27
28	0.0566027	0.0600130	0.0635208	0.0671225	0.0708144	0.0745926	0.0823919	28
29	0.0554454	0.0588799	0.0624146	0.0660455	0.0697686	0.0735796	0.0814487	29
30	0.0543713	0.0578301	0.0613915	0.0650514	0.0688054	0.0726489	0.0805864	30
31	0.0533724	0.0568554	0.0604435	0.0641321	0.0679167	0.0717922	0.0797969	31
32	0.0524415	0.0559486	0.0595632	0.0632804	0.0670952	0.0710023	0.0790729	32
33	0.0515724	0.0551036	0.0587445	0.0624900	0.0663347	0.0702729	0.0784081	33
34	0.0507597	0.0543148	0.0579819	0.0617554	0.0656296	0.0695984	0.0777967	34
35	0.0499984	0.0535773	0.0572705	0.0610717	0.0649749	0.0689739	0.0772340	35
36	0.0492842	0.0528869	0.0566058	0.0604345	0.0643664	0.0683948	0.0767153	36
37	0.0486133	0.0522396	0.0559840	0.0598398	0.0637999	0.0678574	0.0762369	37
38	0.0479821	0.0516319	0.0554017	0.0592842	0.0632722	0.0673581	0.0757951	38
39	0.0473878	0.0510608	0.0548557	0.0587646	0.0627799	0.0668938	0.0753868	39
40	0.0468273	0.0505235	0.0543432	0.0582782	0.0623203	0.0664615	0.0750091	40
41	0.0462982	0.0500174	0.0538616	0.0578223	0.0618909	0.0660589	0.0746596	41
42	0.0457983	0.0495402	0.0534087	0.0573947	0.0614893	0.0656834	0.0743359	42
43	0.0453254	0.0490899	0.0529824	0.0569933	0.0611134	0.0653331	0.0740359	43
44	0.0448777	0.0486645	0.0525807	0.0566163	0.0607613	0.0650061	0.0737577	44
45	0.0444534	0.0482625	0.0522020	0.0562617	0.0604313	0.0647005	0.0734996	45
46	0.0440511	0.0478821	0.0518447	0.0559282	0.0601218	0.0644149	0.0732600	46
47	0.0436692	0.0475219	0.0515073	0.0556142	0.0598313	0.0641477	0.0730374	47
48	0.0433065	0.0471807	0.0511886	0.0553184	0.0595585	0.0638977	0.0728307	48
49	0.0429617	0.0468571	0.0508872	0.0550397	0.0593023	0.0636636	0.0726385	49
50	0.0426337	0.0465502	0.0506022	0.0547767	0.0590615	0.0634443	0.0724599	50
51	0.0423216	0.0462589	0.0503323	0.0545287	0.0588350	0.0632388	0.0722937	51
52	0.0420243	0.0459821	0.0500768	0.0542945	0.0586219	0.0630462	0.0721390	52
53	0.0417410	0.0457192	0.0498347	0.0540733	0.0584213	0.0628655	0.0719951	53
54	0.0414709	0.0454691	0.0496052	0.0538644	0.0582325	0.0626960	0.0718611	54
55	0.0412132	0.0452312	0.0493875	0.0536669	0.0580546	0.0625370	0.0717363	55
56	0.0409673	0.0450049	0.0491811	0.0534801	0.0578870	0.0623877	0.0716201	56
57	0.0407325	0.0447893	0.0489851	0.0533034	0.0577290	0.0622474	0.0715118	57
58	0.0405081	0.0445840	0.0487990	0.0531363	0.0575801	0.0621157	0.0714109	58
59	0.0402937	0.0443884	0.0486222	0.0529780	0.0574396	0.0619920	0.0713169	59
60	0.0400886	0.0442019	0.0484543	0.0528282	0.0573071	0.0618757	0.0712292	60

TABLE 37.—*Bid on a bond for $100 to realize a given net income, interest payable semiannually.*

INTEREST 3½%.

Net income.	5 years.	10 years.	15 years.	20 years.	25 years.	30 years.
3.00	102.31	104.29	106.00	107.48	108.75	109.85
3.10	101.84	103.42	104.77	105.93	106.92	107.78
3.20	101.38	102.55	103.55	104.41	105.14	105.76
3.30	100.91	101.69	102.35	102.91	103.39	103.79
3.40	100.46	100.84	101.17	101.44	101.68	101.87
3.50	100.00	100.00	100.00	100.00	100.00	100.00
3.60	99.55	99.17	98.85	98.58	98.36	98.17
3.70	99.09	98.34	97.71	97.19	96.76	96.39
3.80	98.65	97.52	96.59	95.82	95.19	94.66
3.90	98.20	96.71	95.49	94.48	93.65	92.96
4.00	97.75	95.91	94.40	93.16	92.14	91.31
4.10	97.31	95.12	93.33	91.86	90.67	89.70
4.20	96.87	94.33	92.27	90.59	89.23	88.12
4.30	96.44	93.55	91.22	89.34	87.82	86.59
4.40	96.00	92.78	90.19	88.11	86.44	85.09
4.50	95.57	92.02	89.18	86.90	85.08	83.63
4.60	95.14	91.26	88.18	85.72	83.76	82.20
4.70	94.71	90.51	87.19	84.55	82.46	80.80
4.80	94.28	89.77	86.21	83.40	81.19	79.44
4.90	93.86	89.04	85.25	82.28	79.95	78.12
5.00	93.44	88.31	84.30	81.17	78.73	76.82

INTEREST 4%.

Net income.	5 years.	10 years.	15 years.	20 years.	25 years.	30 years.
3.00	104.61	108.58	112.01	114.96	117.50	119.69
3.10	104.14	107.69	110.73	113.34	115.58	117.50
3.20	103.67	106.80	109.47	111.75	113.70	115.35
3.30	103.20	105.92	108.23	110.19	111.85	113.27
3.40	102.74	105.05	107.00	108.66	110.05	111.23
3.50	102.28	104.19	105.80	107.15	108.29	109.24
3.60	101.82	103.33	104.60	105.67	106.56	107.30
3.70	101.36	102.49	103.43	104.21	104.87	105.41
3.80	100.90	101.65	102.27	102.78	103.21	103.56
3.90	100.45	100.82	101.13	101.38	101.59	101.76
4.00	100.00	100.00	100.00	100.00	100.00	100.00
4.10	99.55	99.19	98.89	98.64	98.45	98.28
4.20	99.11	98.38	97.79	97.31	96.92	96.61
4.30	98.66	97.58	96.71	96.00	95.43	94.97
4.40	98.22	96.79	95.64	94.72	93.97	93.37
4.50	97.78	96.01	94.59	93.45	92.54	91.81
4.60	97.35	95.23	93.55	92.21	91.14	90.29
4.70	96.91	94.47	92.53	90.99	89.77	88.80
4.80	96.48	93.71	91.52	89.79	88.42	87.35
4.90	96.05	92.95	90.52	88.61	87.11	85.93
5.00	95.62	92.21	89.53	87.45	85.82	84.55

INTEREST 4½%.

Net income.	5 years.	10 years.	15 years.	20 years.	25 years.	30 years.
3.00	106.92	112.88	118.01	122.44	126.25	129.54
3.10	106.44	111.96	116.69	120.75	124.23	127.22
3.20	105.96	111.05	115.39	119.09	122.26	124.95
3.30	105.49	110.15	114.11	117.47	120.32	122.74
3.40	105.02	109.26	112.84	115.87	118.43	120.59
3.50	104.55	108.38	111.59	114.30	116.57	118.48
3.60	104.08	107.50	110.36	112.75	114.75	116.43
3.70	103.62	106.64	109.15	111.24	112.98	114.42
3.80	103.16	105.78	107.95	109.74	111.23	112.47
3.90	102.70	104.93	106.77	108.28	109.53	110.56
4.00	102.25	104.09	105.60	106.84	107.86	108.69
4.10	101.79	103.25	104.45	105.42	106.22	106.87
4.20	101.34	102.43	103.31	104.03	104.62	105.09
4.30	100.89	101.61	102.19	102.66	103.05	103.35
4.40	100.44	100.80	101.09	101.32	101.51	101.66
4.50	100.00	100.00	100.00	100.00	100.00	100.00
4.60	99.56	99.21	98.93	98.70	98.52	98.38
4.70	99.12	98.42	97.86	97.43	97.08	96.80
4.80	98.68	97.64	96.82	96.17	95.66	95.26
4.90	98.25	96.87	95.79	94.94	94.27	93.75
5.00	97.81	96.10	94.77	93.72	92.91	92.27

TABLE 37.—*Bid on a bond for $100 to realize a given net income, interest payable semiannually*—Continued.

INTEREST 5%.

Net income.	5 years.	10 years.	15 years.	20 years.	25 years.	30 years.
3.00	109.22	117.17	124.02	129.92	135.00	139.38
3.10	108.74	116.23	122.65	128.16	132.89	136.93
3.20	108.26	115.30	121.31	126.44	130.81	134.55
3.30	107.78	114.38	119.99	124.75	128.79	132.22
3.40	107.30	113.47	118.68	123.08	126.80	129.94
3.50	106.83	112.56	117.39	121.45	124.86	127.72
3.60	106.35	111.67	116.12	119.84	122.95	125.55
3.70	105.88	110.78	114.86	118.26	121.08	123.44
3.80	105.42	109.91	113.62	116.70	119.26	121.37
3.90	104.95	109.04	112.40	115.18	117.47	119.35
4.00	104.49	108.18	111.20	113.68	115.71	117.38
4.10	104.03	107.32	110.01	112.20	113.99	115.45
4.20	103.57	106.48	108.84	110.75	112.31	113.57
4.30	103.12	105.64	107.68	109.33	110.66	111.74
4.40	102.67	104.81	106.54	107.93	109.04	109.94
4.50	102.22	103.99	105.41	106.55	107.46	108.19
4.60	101.77	103.18	104.30	105.19	105.91	106.47
4.70	101.32	102.37	103.20	103.86	104.38	104.80
4.80	100.88	101.57	102.12	102.55	102.89	103.16
4.90	100.44	100.78	101.05	101.27	101.43	101.56
5.00	100.00	100.00	100.00	100.00	100.00	100.00
INTEREST 6%.						
3.50	111.38	120.94	128.98	135.74	141.43	146.20
3.60	110.89	120.01	127.63	134.01	139.34	143.81
3.70	110.41	119.08	126.30	132.30	137.30	141.47
3.80	109.93	118.16	124.98	130.63	135.30	139.18
3.90	109.46	117.25	123.68	128.98	133.34	136.94
4.00	108.98	116.35	122.40	127.36	131.42	134.76
4.10	108.51	115.46	121.13	125.76	129.54	132.63
4.20	108.04	114.58	119.88	124.19	127.70	130.54
4.30	107.58	113.70	118.65	122.65	125.89	128.50
4.40	107.11	112.83	117.43	121.14	124.11	126.51
4.50	106.65	111.97	116.23	119.65	122.38	124.56
4.60	106.19	111.12	115.05	118.18	120.67	122.66
4.70	105.73	110.28	113.88	116.74	119.00	120.80
4.80	105.28	109.44	112.73	115.32	117.36	118.98
4.90	104.83	108.61	111.59	113.92	115.76	117.20
5.00	104.38	107.79	110.47	112.55	114.18	115.45
5.25	103.26	105.78	107.72	109.22	110.38	111.27
5.50	102.16	103.81	105.06	106.02	106.75	107.31
5.75	101.07	101.88	102.49	102.95	103.29	103.55
6.00	100.00	100.00	100.00	100.00	100.00	100.00

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(PROFESSIONAL PAPER.)

SOME DISTINCTIONS IN OUR CULTIVATED BARLEYS WITH REFERENCE TO THEIR USE IN PLANT BREEDING.

By HARRY V. HARLAN,
Agronomist in Charge of Barley Investigations, Office of Cereal Investigations.

INTRODUCTION.

When the writer began active operations in barley breeding in 1909, the intelligent selection of mother plants was found to be very difficult because of the lack of sufficient information to enable minor variations to be recognized and interpreted. European breeders had subjected the taxonomic details to a most exacting scrutiny, but their results were not immediately useful. It was necessary to confirm the European findings, for a character found stable there could not be considered stable under the widely varying climatic conditions of America until it had been so proved. Again, the European authorities were far from united. There was not even a broad taxonomic character whose stability had not been questioned at one time or another, and often by the highest authorities in barley classification. Moreover, even if the groundwork could have been adopted entire, the more or less established taxonomic characters are only the beginning of the problem. Breeding must take note of characters that are trivial in taxonomy. The intangible must be analyzed and made to serve, as well as the tangible.

Even the very plausible idea of adopting European methods and importing improved European stocks was only partially successful. Conditions in America differ in one vital particular from conditions in Europe. On the Continent and in Great Britain barley has been cultivated for centuries, and it is therefore practically indigenous. Each geographical locality has, through long periods of time, been provided by natural selection and acclimatization with superior native races. Breeding, under such conditions, is largely concerned with the improvement of these existing stocks, with small likelihood of any importation proving to be a serious competitor.

NOTE.—A large part of the data herein presented was obtained in cooperation with the Minnesota Agricultural Experiment Station, and the article itself was submitted as a thesis as required for the degree of doctor of science in the University of Minnesota. The subject is of interest to plant breeders and agronomists.

In America there are no native stocks. The grain-producing areas are relatively new. The varieties peculiar to a section are usually the result of chance introductions. Breeding material from foreign sources is as likely to contain desirable types as is that already at hand. In this investigation, in order to obtain the proper basis upon which to conduct breeding work, stocks were assembled not only from local sources but from all over the world. Many distinct strains were isolated from each stock, for both the local varieties and the foreign introductions were usually either races that had not been purified or that had become mixed after purification. The isolation was accomplished by head and plant selections, which when grown in pedigree rows formed a surprisingly large collection. When to these were added a still greater number from the progeny of hybrids, the problem became one of elimination. The plant selections from their very nature were made more or less arbitrarily, and hundreds of these forms were necessarily duplicates. These duplicates, especially as long as they were not so recognized, were a drain upon the breeder, and it was soon realized that the efficiency of a nursery was measured, not by the number of stocks it carried but by the number it eliminated.

It was to accomplish this reduction better that the character studies were made. The distinctions found were of two classes, morphological and physiological. The morphological variations were, in the broader divisions, of taxonomic value, and many of them were practically invariable. The physiological characters were, from their nature, more difficult to appraise. They were found to possess not only more widely fluctuating limits, but the limits often overlapped and at times the characters became inseparable. In physiological characters a further distinction was made between permanent and place variations. Some separations were so wide that they never became confusing, while others became evident only when grown under certain conditions of soil and climate. Such distinctions are worthless as taxonomic features, but have proved very valuable as indications of individual qualities in breeding. Even the lack of stability in a character does not destroy its usefulness, as the tendency of a strain to behave in a certain manner under certain conditions may mark an inherent difference.

It is realized that distinctions of this kind are only a part of plant breeding, and it is not thought that that part is clarified in any great measure. In this paper are given a few of the observations that have been found useful in barley breeding, and with them many that have been found useless. The data upon which the conclusions are based consist of some 200,000 recorded observations, extending over a period of five seasons and embracing experiments at St. Paul, Minn.; Williston and Dickinson, N. Dak.; Highmore, S. Dak.; Moccasin, Mont.; Aberdeen and Gooding, Idaho; and Chico, Cal. Of the work done at these points, that at St. Paul, Minn., which was conducted in cooperation with the State experiment station, was the most extensive.

REVIEW OF THE LITERATURE.

Although the literature of barley is, with the possible exception of wheat, more extensive than that of any other cereal crop, the publications bearing directly upon the theme of this paper are comparatively few. The great mass of the European publications, especially the German ones, have to do with the malting quality of barley. They are concerned mostly with its chemical constituents, the effect of soil, climate, and culture upon the nature and composition of the grain, and the behavior of the converting enzyms in grains of different character. The same is true of papers on the morphology of the grain, and even many of the publications treating directly of barley breeding have little bearing upon the present discussion, as they are often concerned only with the correlation of characters or with the behavior of hybrids. It is only the papers dealing with the taxonomic features of barley, and experiments such as those of the Swedish Plant-Breeding Association at Svalof, which have had for their end the isolation of plant variants, that are of particular pertinence.

The first comprehensive systematic work was that of Körnicke (15)[1], who described 44 botanical forms of barley, using spikelet fertility, color, nature of the awn and glume, and the adherence or nonadherence of the palea. His groups will undoubtedly form the bases of all future classifications. The classification of Voss (25) is important largely because he based a part of it upon the extent of overlapping of the grains, thus forecasting in an indefinite way the use of density. Atterberg (2) made use of the bristle and nerve characters discovered by Neergaard, mentioned below, and subdivided the previous groups until he had 188 named botanical varieties. Beaven (3), by a rearrangement and compilation of previous classifications and by growing and describing a large number of hybrids of Karl Hansen, Körnicke, and others, gave a very clear conception of the entire species. His work is perhaps most valuable in the placing of the Abyssinian forms with abortive lateral florets in a group by themselves. He does not make use of the finer subdivisions employed by Atterberg. Regel (21), on the contrary, carries the subdivision still farther and uses twisting of the spike and earliness and lateness of the variety in his separations. The last, a purely physiological phase, he employs in named botanical forms.

A review of the work at Svalof is especially valuable in this connection because of the fact that a large part of that effort has been

[1] The figures in parentheses refer to the bibliography at the end of the bulletin.

along the same line and because, in many instances, this investigation has merely attempted to discover whether results obtained by them were sustained under the great variations of the American climate. In barley the greatest achievement at Svalof was the discovery of two kernel characters, which, by various combinations, gave four separations under each previous group.

These investigators found that the rachilla in some barleys was covered with long straight hairs and in others with short curly ones; also that the inner pair of dorsal nerves sometimes bore teeth and were sometimes smooth. The stability of these characters was questioned by Broili (10), who claimed to have frequently observed one form in the progeny of another. Tschermak (13), Blaringhem (7), and others have supported the investigators of the Plant-Breeding Association at Svalof, at least so far as the basal bristle is concerned. Although none are to be compared with this discovery in importance, many other studies have been made at Svalof. At one time they had developed a very elaborate system of measurements made by means of many ingenious mechanical devices. They have, unfortunately, made no specific, comprehensive publication of their negative results, but according to Newman (20) and others they have abandoned the use of many of the measurements that were formerly made. Of those retained, the most important from the standpoint of this paper is that of density. In the early history of the association two or three varieties were obtained by the "élite" method. They chose an arbitrary density and made mass selections of spikes conforming to that measurement. Later, they used density as a means of valuing head measurements, as a long head if loose might contain no more grains than a short one if compact. They finally employed it in varietal description. Blaringhem (7), who has followed the work of the Svalof association quite closely, used density as an indication of purity and to reveal the effect of climate.

The morphological characters of the seed coat and the kernel have been treated by Kudelka (16) and Johannsen (14), but there is no suggestion of usable varietal differences.

The composition of the grain has been studied by a few American and a large number of European scientists. Le Clerc and Wahl (17), who have made the most comprehensive of the American studies, have clearly demonstrated that composition is of slight use as a varietal character for, while there are differences, the effect of location and season is many times greater than that of variety.

Color in barley has been employed by all systematists, but has received very little analytical attention. Brown (11) has a note on the color in the variety *coerulescens*, and numerous authors have discussed the occurrence of pigments in other plants. A recent article by Wheldale (26) treats of the chemical nature of anthocyanin and traces its origin from a glucosid.

THE RATE OF DEVELOPMENT.

The rate of development, like all physiological characters, is subject to considerable fluctuation within the strain. The distinctions are naturally much less absolute than those founded upon morphological characters. They have, however, the advantage that they permit a greater number of separations. A plant structure usually has but two phases. It exists or it does not exist. With physiological characters this is not the case. The length of time required for one variety to mature may differ three days from that of a second or it may differ three weeks. From the standpoint of observation, the development of the plant is divided into three periods: (1) The early development from germination to the time of jointing, (2) the period of heading, and (3) the period of maturity.

EARLY DEVELOPMENT.

For some time the writer has maintained that the early growth is the stage of development at which selections of barley are most easily distinguishable. This period seems to have been neglected by plant breeders. There are few records of notes taken during this time, and even those breeders who have known the cereal crops best have based their selections at this period on an intangible something that enabled them to single out any new variation.

During the summer of 1913 an attempt was made to analyze the intangible, with most encouraging results. In addition to careful observations on several hundred selections, 1,400 plants were chosen in the nursery and 1,700 in drill rows, upon which exact records were kept. One hundred plants were used in each variety. The data included the day upon which each of the 3,100 plants produced its second, third, and fourth leaves and its first tiller. The optically plausible became mathematically evident, and it was soon seen that, aside from the leaf character, there was ample justification for the separations made on appearance during the early stages of growth. As figure 1 shows, the selections rush through the early stages at an astonishing rate. A centgener which is only two days, or even one day, behind a second may be in an entirely different stage of development and may therefore present an appearance which in no way resembles that of the first. Yet the two barleys may be closely related strains and inseparable or separated with difficulty at maturity. The typical curves of the production of the second, third, and fourth leaves are always very sharp. In figure 1 the curve of tillering is more flat than is usually the case. The first of the third leaves emerges about the time of the appearance of the last of the second. The fourth leaf is produced in about the same relation to the third, but perhaps a little earlier. The first tillers are usually simultaneous with the fourth leaves, though in some varieties they appear earlier.

The tillering in most varieties is not completed as rapidly as is the production of the fourth leaf, and it is deterred by disease much more than is the leaf.

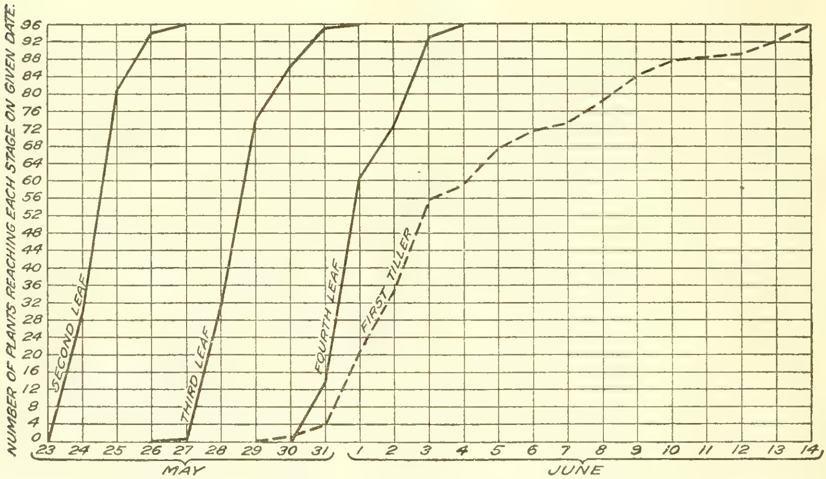

FIG. 1.—Curves showing the production of the second, third, and fourth leaves and of the first tiller in 96 plants of Oderbrucker barley (selection No. 50).

Besides the difference in dates there is a difference in method of production. In some varieties the curve of each stage is very acute and the stage is completed in a few days. In others it is more obtuse

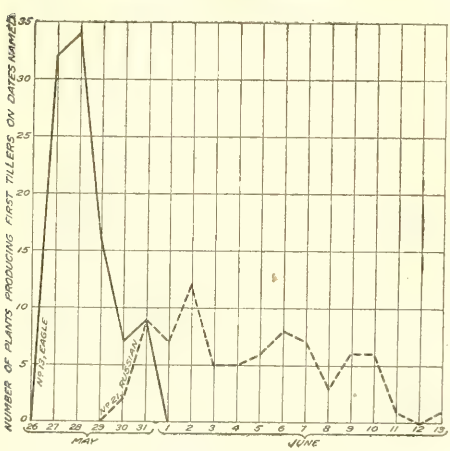

FIG. 2.—Curves showing varietal differences in the rapidity of tillering of barley selections. In Eagle (No. 13) all plants produce tillers almost simultaneously, while in Russian (No. 21) the process is extended over many days.

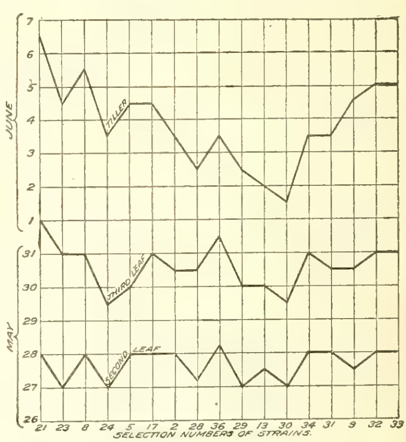

FIG. 3.—Curves showing the average date of the production of the second and third leaves and of the first tiller in 100 plants of each of 17 selections of barley grown in drill rows.

and the time for completion extended. Figure 2 shows the relative rapidity of stooling in two selections, the one of the first type and the other of the second.

Differences are revealed in two ways by a comparison of the behavior of strains. There is an actual difference of date in any stage and, still more important, a relative difference between various stages. This is shown to some degree in figure 3, and to a still greater degree in figure 7, which will be discussed later. Figure 3 shows the date upon which the greatest number of plants in 17 selections sown in drill rows reached the three stages of development. It will be noticed that the average date of the occurrence of the second leaf varied over scarcely more than 1 day, while the third extends over 2½ days, and the production of tillers over 5 days. No. 5, for instance, produces the third leaf 2 days after the second, while No. 13 requires another half day. Yet No. 13 requires but 3 additional days to produce tillers, while No. 5 requires 5½ days.

EMERGENCE OF THE AWNS.

The time of heading is a general agronomic note, and there is no doubt that an observation of this period is of great value in plant breeding. Distinctions at this time should be easily made and should be more reliable than those of any later date. The difference between selections is greater than in the earlier stages, and the effect of season is not apparent in any abnormal hastening of development, as it is later in ripening. In any climate, most barleys develop in a fairly normal manner until flowering time. The time of heading, for these reasons, should be of great use. It has, however, one disadvantage. It is an extremely difficult note to obtain, and hence inaccurate. Barleys differ very much in their manner of heading. Some heads are exserted rapidly and completely, others slowly and only partially. The observer has not only the difficulty of maintaining an arbitrary mental standard, but is confronted by numerous exceptions that never conform to any standard.

In a study of this difficulty it was noticed that just previous to heading, the tips of the awns in all awned varieties projected from the boot of all plants in the selection with suggestive uniformity. The date of the emergence of the awns was substituted for the date of heading, with excellent results. The personal error was immediately removed and, as the facts could be gathered at a glance, the note taking was greatly accelerated. The change made a valuable plant-breeding observation out of a dubious agronomic note.

Analyzed, the curve of date of emergence of the awns is almost as sharp as those representing the production of the leaves and tillers. Figure 4 shows the curve of 13,108 plants, a summary of the observations of a large number of selections. It will be noticed that nearly two-thirds of the plants pass through this stage in two days. A difference of a single day serves to change the appearance of a whole centgener, and strains that are three days apart are unbelievably dissimilar when viewed at this time.

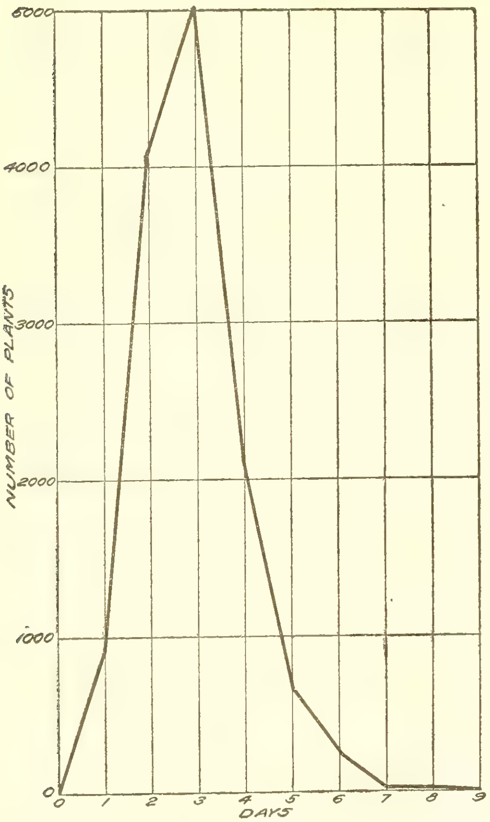

FIG. 4.—Curve showing summary of data on the emergence of the awns in 13,108 plants from various selections of barley.

This note was taken for a large number of selections for three years to test the transmissions of slight variations in earliness and lateness. The evidence seemed all in favor of accrediting to this character a heritability equal to that of most plant characters. The data are too cumbersome to include entire, but a random selection of strains of one general type is given in figure 5. The variations are parallel, on the whole, especially when it is remembered that the centgeners were often separated by considerable distances, allowing variations in soil and moisture. The exceptions are fully as likely to represent differences in the character of the strains, causing them to respond differently to different seasons, as they are to question the value of the note.

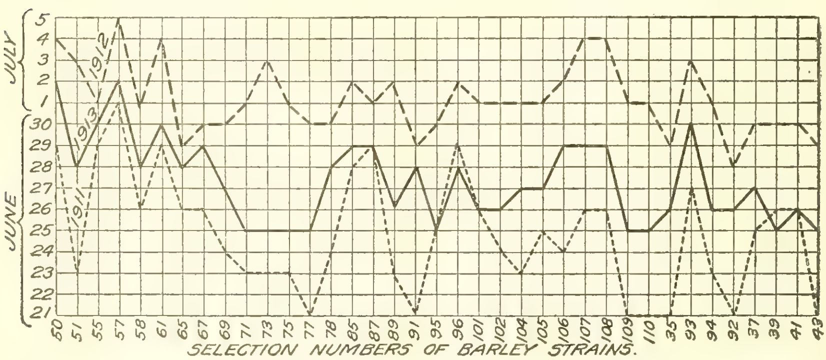

FIG. 5.—Curve showing the effect of season upon the relative date of the emergence of the awns in 37 selections of 6-rowed barley grown at St. Paul, Minn., in 1911, 1912, and 1913.

DATE OF RIPENING.

The date of ripening is a note universally taken. While less dependable than the emergence of the awns, it is a very useful observation. Within a strain the plants mature quite uniformly. In order to determine the amount of such variation, the exact date of maturity of each spike in a plat of Manchuria barley was recorded. The spikes were considered ripe when the last traces of green disappeared from the glumes. In order to avoid confusion, they were harvested as fast as they ripened. The result is shown in figure 6. The curve is very sharp, almost half the product of the plat maturing upon the same day.

The weakness of the note is in the abnormal ripening of varieties. In Minnesota the observation is quite dependable in Manchuria forms, but is likely to be much less so in the 2-rowed varieties. Some of the latter mature in a normal manner, while others, especially the later ones, half ripen and half die. Also, a rain at this period has much more influence in the development than at other times in the life of the plant.

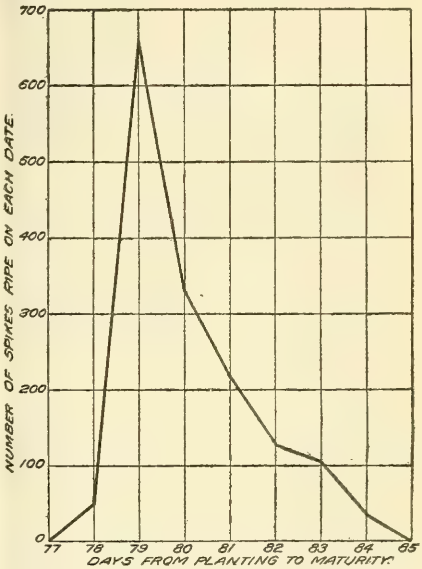

FIG. 6.—Curve showing the ripening of 1,541 spikes in a plat of Manchuria barley, stated in days from date of planting.

COMPARATIVE RATES OF DEVELOPMENT.

Although separations can be made by a study of any one of these stages, it is only when the entire seasonal histories of the selections are compared that the full variation is apparent. Figure 7 shows the development of 14 strains from the production of the second leaf until maturity. Each stage was obtained by actual count of all the normal plants in each centgener, usually between 90 and 100.

The relation of the earlier stages has already been commented upon. It will be noticed that the tillers are produced usually after the fourth leaves. In Nos. 34, 13, and 24 this is not the case, and these three selections are definitely distinct from the other eleven by this different habit of tillering. Nos. 21 and 57 are parallel in the earlier stages but are widely separated in the emergence of the awn. No. 29 is one of the earliest of all the selections to produce the second leaf, and yet it is among the very latest in maturity. Indeed, there is some peculiarity about each one of the fourteen when all stages are considered.

VARIATIONS IN THE CULM.

The culm varies in length, diameter, thickness of walls, exsertion of spike, number of nodes, and number of culms per plant.

LENGTH OF THE CULMS.

The height of the plant is a note universally taken on all experimental farms. At any chosen station, some varieties are always tall and others always short. This distinction is sufficient to prove a difference between such varieties, and as such it is a useful observation in breeding. It is, however, merely a proof that a difference exists and is not necessarily a difference in itself. There is a physiological adaptation of varieties to certain places and it may express itself in height.

In 1911 thirteen pedigreed selections, representing nine minor groups of barley, were chosen from the nursery stock and planted at four widely separated points. At maturity the length of culm was carefully noted. The influence of climate and soil was surprisingly great. As will be seen in Table I, there is a marked regional response. The selection of Odessa is a *Hordeum sativum hexastichum* form occurring in the commercial Odessa variety. In Minnesota it is short and unpromising. In California it is little better, while in the north Rocky Mountain and Plains areas it displays an unexpected vigor and is very tall. The Abyssinian varieties grow well in California, but are short elsewhere.

FIG. 7.—Curves showing the date of the production of the second, third, and fourth leaves and the first tiller, the emergence of the awns, and the day of ripening in 14 selections of barley grown at St. Paul, Minn., in 1913. Each determination was based on one centgener of approximately 100 plants.

TABLE I.—*Influence of geographical location on the length of the culm in 13 representative selections of barley grown at four widely separated points, the selections being arranged in the order of their height at each point.*

St. Paul, Minn.	Williston, N. Dak.	Moccasin, Mont.	Chico, Cal.
Hordeum vulgare	Servian	Odessa	S. P. I. No. 20375.
Oderbrucker	Odessa	Hordeum vulgare	Oderbrucker.
Manchuria	Hordeum vulgare	Surprise	Abyssinian.
Summit	Smyrna	Summit	Servian.
Princess	Oderbrucker	Servian	Smyrna.
Surprise	Manchuria	S. P. I. No. 20375	Manchuria.
Servian	Summit	Kitzing, 6-rowed	Summit.
S. P. I. No. 20375	Surprise	Manchuria	Odessa.
Kitzing, 2-rowed	Kitzing, 6-rowed	Oderbrucker	Kitzing, 6-rowed.
Kitzing, 6-rowed	S. P. I. No. 20375	Smyrna	Princess.
Abyssinian	Princess	Abyssinian	Kitzing, 2-rowed.
Smyrna	Abyssinian	Kitzing, 2-rowed	Surprise.
Odessa	Kitzing, 2-rowed	Princess	Hordeum vulgare.

The great variation evidenced by these few selections is sufficient to show that the length of culm can not be of much taxonomic value. There are varieties which are persistently below average height, and others that are as persistently above, but beyond that it is difficult to make an unqualified statement. Locally, this measurement is of more significance and can often be used to advantage in the study of nursery selections. The differences it reveals are important in breeding, no matter to what cause they may be due.

DIAMETER OF THE CULMS.

Measurements have not been found very useful in revealing small differences in the diameter of the culm. The experimental error is large, owing to the fact that the diameter varies on the same plant with the culm selected, on the same culm with the internode chosen, and on the same internode with the distance from the node. A part of this variation was avoided by measuring the greatest diameter of the first elongated internode, but even then the results were unsatisfactory. There are varietal differences, but they must be great enough to be seen optically before the error of measurement is reduced to the point where it becomes negligible. As a group, the *nutans* has smaller culms than the Manchuria, but among the Manchuria strains there is little difference. Only once in these investigations has this character been used to isolate a type. This type has proved to be stable, and perhaps the effort of measuring hundreds of selections is rewarded by the one strain obtained, as it is very promising.

THICKNESS OF CULM WALLS.

A large number of determinations were made of the thickness of the walls of the culm, with even less satisfaction than in those of the diameter. Measurements finer than one-tenth of a millimeter are impracticable, owing to the variation within the plant and culm. This does not give range enough to disperse the varieties. For instance, of 242 selections of 6-rowed barley, the culms of 153 measured 0.5 mm. in thickness and only 33 deviated more than 0.1 mm. from this figure.

THE EXSERTION OF THE SPIKE.

The exsertion of the spike is closely related to the length of culm because it depends upon the elongation of the peduncle. Some barleys clear the boot much more completely than others. That this is a true varietal character is shown by the number of varieties in which it has been described. The Princess in Sweden is often included at the base. The same is true of this variety in Minnesota and California. The Smyrna seldom clears the boot completely in more than one or two culms on each plant. An interesting fact was noted in this variety with reference to location. In Minnesota, half the head often remains in the boot, and the same condition prevails over the whole of the Plains area. In California, however, the heads are completely exserted. The exsertion is still short as compared with most varieties, but it is perfect. Like other physiological characters, the exsertion of the spike is variable, but its range of variation is sufficiently limited to occasionally determine a variety. That it is not more often useful is due to the fact that almost all barleys are of the type in which the spike is completely exserted.

NUMBER OF NODES PER CULM.

The number of nodes to the culm is naturally identical with the number of leaves to the culm and is discussed under that heading.

NUMBER OF CULMS PER PLANT.

The number of culms per plant seems to be a varietal character, but one which is so dominated by environment as to make it impossible to determine when it is given true expression. It is probable that all students of the cereals have gone through the same process of diminishing confidence to final doubt as to the utility of this factor. In this investigation the number of tillers was recorded on over 20,000 plants without being able to discover a method of using such information for minor distinctions, as was possible, for instance, with the time and method of tillering. The broad groups vary as groups in this character and occasionally a variety deviates sufficiently from its group to become distinct, but the mass is, for the most part, inseparable.

Two causes of variation were studied in detail, viz, spacing and geographical location. In Minnesota a selection of Smyrna, a heavy-tillering variety of a 2-rowed group, and a light-tillering selection of Manchuria of the 6-rowed group were planted at three different spacings. The results obtained are shown in Table II. As will be seen in this table, the varieties remained distinct in their tillering habit, but as the space decreased, the difference of over three culms per plant in favor of Smyrna rapidly diminished to one. Types falling between these extremes were inseparable at the least spacing. It will also be noticed that the varieties differ in the spacing at which they seem to make complete use of the soil. An increase in number of plants in the Manchuria beyond the 4 by 4 inch plantings does not increase the number of tillers on the unit area, while for Smyrna the limit is not yet reached.

TABLE II.—*Effect of interval on the production of culms in selections of Smyrna and Manchuria*[1] *barley.*

Plants and culms.	Space between plants.					
	4 by 8 inches.		4 by 4 inches.		4 by 2 inches.	
	Manchuria.	Smyrna.	Manchuria.	Smyrna.	Manchuria.	Smyrna.
Total plants	42	46	87	80	179	190
Total culms	122	282	234	361	236	446
Culms per plant	2.9	6.1	2.7	4.5	1.3	2.3

[1] The selection of Manchuria was made for its low-tillering habit, and it is not typical of the Manchuria variety as commonly grown.

The response to geographical location is a disturbance sufficient to vitiate all close distinction. Even the groups are often reversed. For instance, when summarized, a large number of selections of 6-rowed barley at St. Paul averaged 2.6 culms per plant, while at Chico the same selections averaged but 1.5. The 2-rowed group, on the contrary, averaged but 4.2 culms at St. Paul, while at Chico it averaged 5.8. The Smyrna, however, stood near the top in both places, showing that in extreme cases the effect of environment does not conceal the character.

LEAF CHARACTERS.

The leaves of mature barley plants present quite a variety of aspects which are, as a whole, hard to record. Most of them are mass effects, and hence treacherous, because of the optical differences due to the angle of observation with reference to the light. This investigation is concerned with four points of variance—the color, the width, the length, and the number of leaves.

COLOR OF LEAVES.

A very casual observation shows a considerable difference in the color of leaves, but there are so many difficulties in their valuation that the writer is unprepared to discuss their separation at this time.

WIDTH AND LENGTH OF LEAVES.

Any study of leaf dimensions must be statistical and therefore difficult to report briefly. The obstacles to the use of such measurements are twofold: The leaf varies with its nourishment and with its exposure, and it is often damaged by the wind. In a study of mature plants, the second leaf from the top being used in all cases, the normal variation was found to be considerable. For instance, at the same place in the same season the leaves of border plants were from 1 to 2 mm. greater in width than those from the interior of the plat, and the length of the leaves of such plants was from 2 to 3 cm. greater. In Princess, one of the least variable varieties, the average size of the leaves of the border plants was 13.7 mm. by 24 cm., and of the interior plants 12.7 mm. by 23 cm.

To be usable in breeding, a note must be reasonably easy to obtain. To test the usefulness of this character, the first 25 of the 100 measurements of each selection were tabulated, as shown in Table III. With width of leaf, the experimental error is small, as width can be determined quite accurately and the broadest part of the leaf is seldom damaged. If the figures, then, are conclusive mathematically, the method is practical. The probable error in the 25 measurements of Princess is ±1.2. It thus fails to separate this variety dependably from Kitzing and Proskowetz, its nearest relatives, or from the selection of *deficiens*, or Odessa. (See Table III.) From the rest, however, the separation is clear enough to be significant. With the two selections of Oderbrucker, the separation is sufficient to establish a difference. In this case the two are closely related and the note becomes serviceable. As a rule, the width of leaf is seldom a sufficient basis for separation in closely related strains. Fortunately, such differences are seldom unaccompanied by other points of variance, and it is often the sum of several differences that serves to distinguish individual strains.

TABLE III.—*Greatest, least, and average width and length of 25 leaves in each of 13 selections of barley grown at St. Paul, Minn., in 1911.*

Pedigreed selection from—	Leaf width.			Leaf length.		
	Greatest.	Least.	Average.	Greatest.	Least.	Average.
	Mm.	*Mm.*	*Mm.*	*Cm.*	*Cm.*	*Cm.*
Princess	15.0	12.5	13.2	28	20.0	23.5
Kitzing, 2-rowed	15.5	11.0	12.7	28	20.0	23.7
Hordeum sativum deficiens	16.0	12.5	13.7	32	26.0	28.7
Oderbrucker	17.5	14.0	15.5	23	17.0	19.2
Manchuria	20.0	14.0	16.7	27	18.0	22.8
Oderbrucker	22.0	15.0	18.7	28	20.0	24.3
Summit	15.5	12.5	14.3	26	18.0	22.5
Kitzing, 6-rowed	20.0	16.5	18.5	26	18.0	22.6
Surprise	20.0	16.5	18.3	26	19.5	22.9
Servian	20.0	15.5	17.8	25	20.0	22.8
Odessa	15.0	11.0	13.7	22	14.0	17.9
Abyssinian	22.0	17.0	18.7	25	20.0	22.0
Proskowetz	16.0	11.0	13.0	28	23.0	25.5

In length of leaf, the method is much less promising. Not only is the probable error greater, but the measurement is unsatisfactory. The leaves become so broken by whipping in the wind that specimens which are entire at the tip are seldom found. An effort was

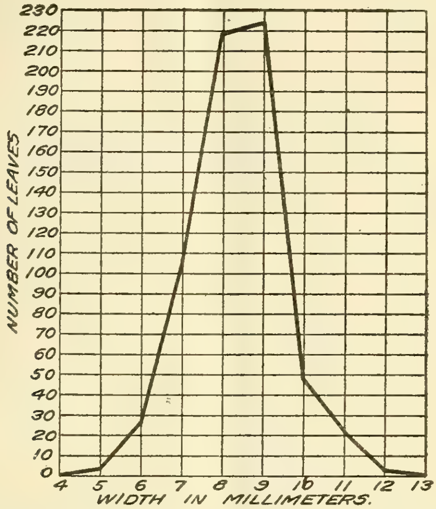

FIG. 8.—Composite curve showing the width of leaves in millimeters in eight selections of barley.

made to overcome this difficulty by choosing an earlier stage of development and thus utilizing the better protected leaves nearer the ground. Although the extreme tendencies were not yet developed, the second leaf from the seedling was found to offer fewer experimental difficulties. Such leaves were entire and the length

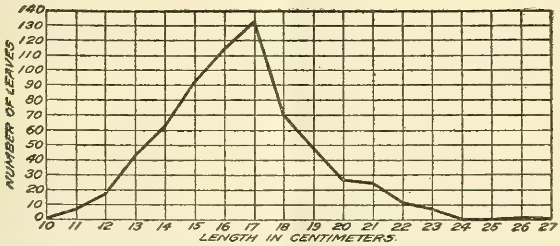

FIG. 9.—Composite curve showing the length of leaves in centimeters in six selections of barley.

measurements accurate, but even then the width was much less variable than the length. All measurements, consisting of 100 leaves of each strain, showed a sharp curve in width, but a flat one in length, the latter sometimes having two summits. Composite curves are shown in figures 8 and 9.

The summary of leaf measurements of 316 pedigreed selections in Table IV shows that the common taxonomic groups, based upon spike characters, are correlated in the nature of their leaf growth.

TABLE IV.—*Summary of measurements of the width and length of barley leaves made at St. Paul, Minn., in 1911, arranged according to the common taxonomic groups.*

Group.	Number of strains.	Leaf width.			Leaf length.		
		Greatest.	Least.	Average.	Greatest.	Least.	Average.
		Mm.	*Mm.*	*Mm.*	*Cm.*	*Cm.*	*Cm.*
Hordeum sativum erectum	11	17	13	14.0	26	22	23.9
Hordeum sativum nutans:							
Long-haired	67	14	9	11.4	27	20	23.0
Short-haired	18	18	10	13.6	28	20	24.2
Hordeum sativum vulgare:							
Manchuria types—							
Long-haired	49	18	13	16.1	25	20	22.6
Short-haired, white	85	20	15	17.7	26	22	23.7
Short-haired, blue aleuron	34	19	14	16.8	25	21	23.3
Russian types	23	19	13	17.0	27	22	23.7
Hordeum sativum hexastichum	29	19	10	15.4	26	19	22.2

NUMBER OF LEAVES.

The number of leaves, excluding, of course, those formed before the appearance of the shoots, is the same note as the number of elongated internodes in the culm. The number of leaves above the basal rosette is a variable, but at the same time rarely a useful distinction in breeding. Strains may be found which are very different, but usually they are not closely related. Thus, in the variety Hannchen the number often drops to three and seldom goes above five. In the selection of *Hordeum sativum hexastichum* the number rarely falls as low as five and is usually six or seven. This distinction, however, is not necessary to separate these forms. In each of several hundred Manchuria selections the number of leaves per culm fell upon either four or five, giving no opportunity for separation.

THE DENSITY OF THE SPIKE.

The writer is inclined to place even more importance upon the density of the spike than has been the tendency of many barley breeders. Aside from its finer distinctions, some of the effects attributed to other characters are in reality due to the length of the internode of the rachis. Most investigators have attributed the difference between *Hordeum sativum vulgare* (*tetrastichum*) and *Hordeum sativum hexastichum* to a difference in fertility. They have considered that in *Hordeum sativum vulgare* the side florets are more reduced than in *Hordeum sativum hexastichum.* This supposition is not borne out by the facts. In the *Hordeum sativum hexastichum* the central row is as favored in nutrition as it is in the *Hordeum sativum* *vulgare*. This is easily demonstrated by weighing kernels from side and central spikelets. In the *Hordeum sativum vulgare* the lateral kernels, compared with the central ones, are actually greater in relative weight than is the case in the *Hordeum sativum hexastichum.*

Differences other than density are likely to be due to the nature of the attachment of the lateral spikelets. Systematists describe the barley spikelets as sessile. This is true in most cases, but it approaches an exception in *Hordeum sativum hexastichum.* In this group the central spikelets are sessile as usual, but the lateral ones either possess an elongation of the base of the flowering glumes or else are pedicellate. Among the barleys collected by the writer is a Greek form in which the lateral spikelets are elevated upon a pedicel that is over one-half as long as the length of the rachis internode itself. This pedicel is jointed both at its attachment to the rachis and at its attachment to the floret. It is the longer attachment of the lateral spikelets that allows the characteristic radial arrangement of *Hordeum sativum hexastichum.* Density is, however, a parallel factor. The compactness of the spike forces the kernels to assume certain relations. Both in *Hordeum sativum hexastichum* and in *Hordeum sativum erectum*, the kernels are placed at a much wider angle with reference to the rachis than in *Hordeum sativum vulgare* and *Hordeum sativum nutans*. The Swedish Plant-Breeding Association at Svalof has considered the angle of the inclination of the kernels as one of the more important of their notes. It is the opinion of the writer, however, that, with rare exceptions, it will vary directly with the density, and is therefore superfluous if the latter measurements be taken.

In breeding, density has not been utilized as fully as its value seems to warrant. Voss (25), Körnicke (15), and Atterberg (2), have used it in group classification, and Atterberg, Blaringhem (8), and the breeders at the Svalof station have used it in studies of variation and purity, but in the opinion of the writer its possibilities in the isolation of types and in the identification of strains have been far from exhausted.

In the years from 1909 to 1913 a close study of density was made, both upon general farms and in experiment-station nurseries. In this study, 100 spikes of each variety were taken without other choice than that they were not diseased or dwarfed. On each of these spikes 10 internodes of the rachis were measured; that is, the distance was between six spikelets on one side of the rachis. From these measurements the number of internodes per decimeter was computed and this number taken as the unit of density. The formula was then $D=1{,}000 \div L$, where L was the length in millimeters of 10 internodes of the rachis.

The use of this formula, while it makes the statement of density more definite, disturbs the natural curve of the measurements to some extent. In all densities below 31 the tendency is to condense the grouping; above that figure the opposite is true. The worst effect—that of bunching the figures when two-length measurements fall upon the same density—was avoided by the use of fractions. None of the curves have been smoothed, however, and it will be noticed that those of the greater densities, especially, are slightly rough. This roughness is more mathematical than real, but it seemed more desirable to present the figures as they were than to make them still more artificial by smoothing them.

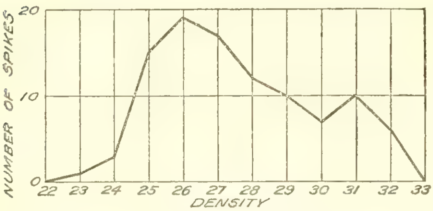

FIG. 10.—Curve showing the density (number of internodes in 1 decimeter) of 100 spikes of Manchuria barley from a field near Excelsior, Minn.

In a pedigreed strain the curve of density is normally sharp, with a single summit. If the seeding is not pure, or if the heads from two plats become mixed, the curve is flattened and is characterized by more than one summit. Although included for another reason, the normal curve of a pedigreed barley is well illustrated in figure 12. When this is compared with the curve of the field sample of Manchuria shown in figure 10, the significance of density is readily appreciated, especially when it is remembered that the Manchuria is what is known as a variety and contains no types that merge into such other 6-rowed varieties as Bay Brewing or Odessa.

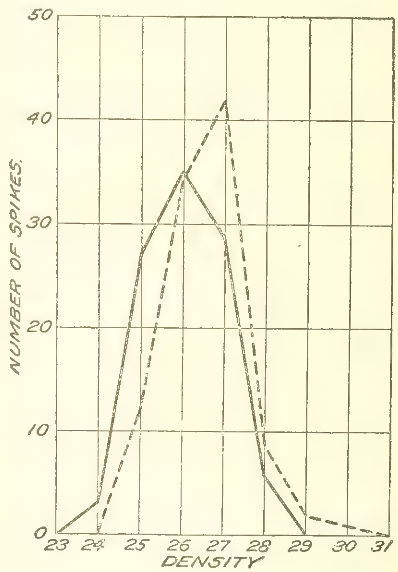

FIG. 11.—Curves showing the density of 100 spikes from two plats of Sandrel (No. 35) barley planted in different parts of the 1913 nursery at St. Paul, Minn.

That density of selections is an accurate and comparable note in a nursery where the object is to obtain like conditions for all selections is shown in figure 11. The Sandrel was included twice in the 1913 planting. The beds were separated by such a distance as to represent the extremes of soil variation in the nursery. The difference in density is very slight.

The summits of the curves are separated by only one unit of density, but even this is seen to be too great when the entire curves are considered. Although the second summit is on 27, there are 46 spikes whose density is less than that number and only 12 whose density is greater. The actual separation is nearer five-tenths of a unit. The degree of separation afforded by a difference of only two internodes to the decimeter is shown in figure 12. These are two selections of Manchuria barley taken at random from Table V. By chance, they are somewhat more ideal than the average strain in the same table. A difference of only two units in density, when taken alone, is perhaps too slight a basis upon which to separate strains, yet, as is shown in the figure, the field of actual merging is very small.

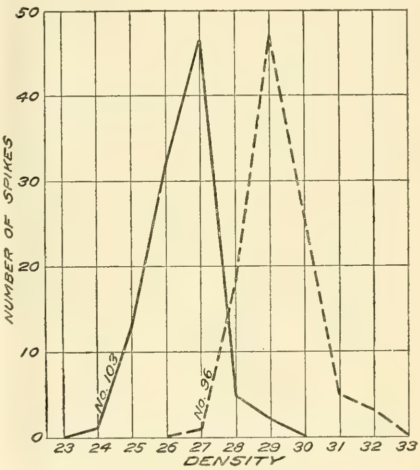

FIG. 12.—Curves showing the density of 100 spikes from two selections of Manchuria barley grown at St. Paul, Minn., in 1913.

The value of this character in the nursery is shown in figure 13. These barleys are all closely related pedigreed strains of Manchuria. Most of them were from head selections made upon farms in southeastern Minnesota. The curve represents the summits of the curves of densities of the individual selections. The variation is considerable and is sufficient to establish some differences of itself. It is, however, only when several characters are compared that the full value of any note is apparent. For this purpose, the date of the emergence of the awn is placed also in figure 13. As they are in no way parallel, the combination of the two curves more than doubles the value of each. It will be noticed that Nos. 3, 6, and 55 are suspiciously similar, the density and the date of emer-

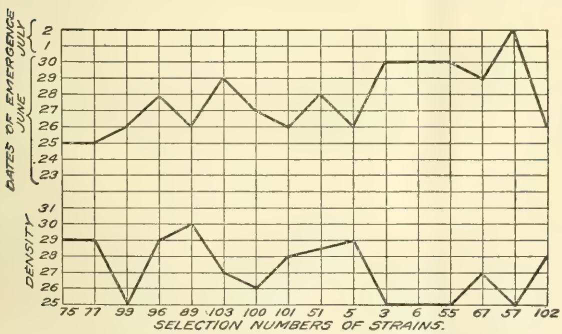

FIG. 13.—Curves showing the average density and the date of emergence of the awns in 16 selections of Manchuria barley grown at St. Paul, Minn., in 1913.

gence of the awns of the three being identical. The records show that the emergence was also on the same date the previous year. No. 55 is proved to be distinct by the nature of the rachilla, but the date of heading, time of stooling, etc., are parallel in Nos. 3 and 6, and there is little doubt that they are identical.

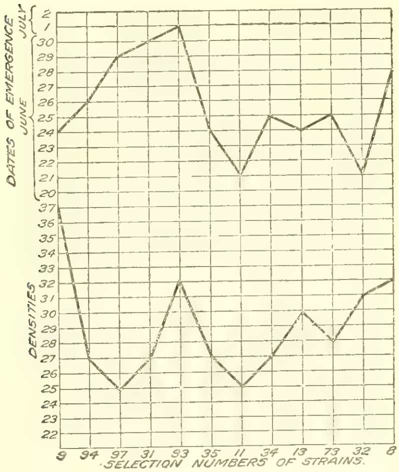

FIG. 14.—Curves showing the average density and the date of emergence of the awns in 12 miscellaneous selections of barley grown at St. Paul, Minn., in 1913.

While not pertinent to this phase of the discussion, the curve of density and the curve of emergence of beards are almost opposite in the Manchuria barley. In other words, there seems to be a direct correlation between density and earliness. In figure 14, in which are assembled a number of other types of 6-rowed barleys that are for the most part not closely related, this is not true.

The first five selections, the densities of which are shown in figure 14, are from a commercial variety known as Odessa. This so-called variety seems to be a loose assemblage of widely varying types, which are, however, ones not common in other 6-rowed barleys. The component strains are not nearly as closely related as are those of the Manchuria. That this variety itself is of hybrid origin or that there has been crossing between its members is indicated in figure 15. This selection, the most dense of those made from the Odessa variety, proved unstable. The number of plants bearing dense heads was 71, as opposed to 16 for the looser ones.

FIG. 15.—Curve showing the density of 134 spikes of Odessa (No. 9) barley grown at St. Paul, Minn., in 1913.

While a character need not be invariable under all conditions in order to be useful, a test was made to discover the effect of soil and climate on density of spike. Six selections were planted at St. Paul, Minn., at Chico, Cal., and at Aberdeen, Idaho. At Aberdeen they were grown both under irrigation and upon dry land. The measurements at St. Paul and at Aberdeen were made by the writer, while those at Chico were made by Mr. E. L. Adams. The result is shown in figure 16. As a whole the variations were parallel, Nos. 6 and 35 being strikingly so. The four less dense selections showed an extreme variation of only three units, while the two dense selections varied much more. In No. 32 this was due in part to poorly developed heads; at St. Paul, particularly, its spikes were so short that it was impossible to find many in which five successive nodes bore fertile florets. The effect of sterility is to lengthen the internode of the rachis. All types were most dense at Chico and least dense at St. Paul. The effect of irrigation as shown at Aberdeen was very slight, especially when compared with the effect of the combined factors of geographical location.

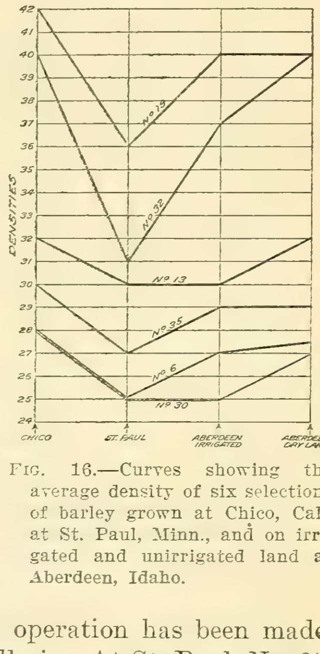

FIG. 16.—Curves showing the average density of six selections of barley grown at Chico, Cal., at St. Paul, Minn., and on irrigated and unirrigated land at Aberdeen, Idaho.

The character of the curves was influenced even less than their relative density. Table V shows the distribution into their various densities of 100 spikes from each of 59 plats of barley. By referring to Table V it will be seen that some selections always present a much sharper curve than others, and thus afford opportunity for varietal distinctions in the distribution of the measurements. Avoiding the extreme examples, it will be noted that the spike of No. 30, for instance, which has already been condensed three or four units by the use of the formula for density, is still less compact than No. 35, which by the same operation has been made to appear slightly less compact than it really is. At St. Paul, No. 35 has a total of 85 per cent of its spikes within three units in one instance and 91 per cent in another, while No. 30 has but 82 per cent within this limit. At Aberdeen, under irrigation, No. 35 has a total of 91 per cent of its spikes within three units, while No. 30 has but 78 per cent; upon the dry farm at the same place, No. 35 has a total of 81 per cent of its spikes within three units, while No. 30 has but 77 per cent; and at Chico, No. 35 has 94 per cent of its spikes within three units, while No. 30 has 91 per cent.

TABLE V.—*Distribution into their various densities of 100 spikes from each of 59 plats of barley.*[1]

Place and name.	Stock No.	Row No.	Number of internodes in one decimeter.																									
			21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
St. Paul, Minn.:																												
Manchuria	11	17			6	33	34	6	1																			
Servian	34	29					15	24	39	9	2																	
Eagle	13	31								3	22	39	27	9														
Sandrel	35	33				3	27	35	29	6																		
Malting	73	67					1	4	30	33	20	9	3															
Odessa	9	23					6	10	15	1	1				2	7	21	30	36	2	2			1				
Mariout	32	25							1	3	7	16	31	24	11	5	1	1										
Steigum	24	32				3	15	23	39	8	2																	
Oderbrucker	75	69						4	19	32	33	10	2															
Meyer	77	71							3	14	36	32	13	2														
Lake City	99	96			1	10	35	34	19	1																		
Triangular	96	93							1	18	47	26	5	3														
Silver King	89	83								4	20	41	26	9														
Sandrel	35	87					12	34	42	9	2	1																
Odessa	94	89					8	28	49	11	4																	
Mahrische	72	66				2	12	34	32	14	6																	
Luth	103	100				1	13	32	47	5	2																	
Lake City	100	97			1	11	35	36	15	1	1																	
Summit	8	41									1	2	11	27	22	20	13	4										
Odessa	97	94		1	10	37	39	11	2																			
Hanna	60	51	14	16	35	28	6	1																				
Do	23	30					17	27	31	14	9	2																
Featherston	101	98					2	2	34	40	18	4																
Meyer	51	45						2	19	34	34	10	1															
Triangular	102	99					1	3	31	37	21	7																
Luth	5	39							2	17	40	28	10	3														
Meyer	3	91		3	8	23	54	10	2																			
Odessa	31	21					8	25	44	12	8	2	1															
Svanhals	19	22												1	1	9	23	35	24	4	3							
Featherston	6	14			1	15	45	25	13	1																		
Odessa	93	88								2	6	19	28	31	10	3	1											
Featherston	55	49		2	5	16	37	24	13	2	1																	
Italian	30	42		6	15	26	41	10	1	..	1																	
Minnesota No. 105	67	61					3	11	30	26	21	6	1	..	1	1												
Chevalier	56	50		1	6	15	41	23	12	2																		
Luth	57	51		1	4	13	44	20	17	1																		
Hannchen	54	52						1	12	27	42	13	3	2														
Excelsior, Minn.:																												
Manchuria	(2)	A			1	3	15	19	17	12	10	7	10	6														
Do	(2)	B			1	3	26	30	25	9	5	1																
Do	(2)	C				1	33	32	29	4	1																	
Do	(2)	D				2	12	21	30	13	13	3	2	2	1	1												
Chico, Cal.:																												
Italian	30	25						3	24	37	30	6																
Mariout	32	28																1	3	7	10	24	13	13	10	10	5	4
Eagle	13	31										1	10	39	24	16	9	1										
Svanhals	19	15																				18	22	34	12	13	1	
Sandrel	35	32									9	51	34	6														
Featherston	6	14						7	35	39	18	1																
Aberdeen, Idaho:																												
Featherston	6	79					3	11	37	31	11	6	1															
Mariout	32	100											1	8	6	11	14	9	20	8	12	9	1	1				
Eagle	13	103						1	1	8	26	30	21	10	2													
Svanhals	19	26													1	..	2	4	23	12	18	24	6	9	..	1		
Italian	30	37		3	8	20	34	24	10	1																		
Sandrel	35	74						1	5	24	47	20	3															
Featherston	6	379					2	9	31	30	18	5	1															
Sandrel	35	374						1	11	20	34	24	6	1														
Italian	30	337		3	3	2	12	30	34	13	3																	
Svanhals	19	326													1	1	5	6	18	14	21	28	2	4				
Mariout	32	400														1	2	4	19	9	14	21	9	13	4	4		
Eagle	13	403								1	5	12	24	45	10	3												

[1] Featherston, Luth, and Meyer are all Manchuria or Oderbrucker barleys, named from the farms upon which the selections were made. Measurements of 134 instead of 100 spikes are given in Odessa No. 9, which broke up into two types. The Excelsior barleys were from general fields, three of which were unpedigreed. At Aberdeen, rows 26 to 103 were irrigated, while rows 326 to 403 were grown upon dry land. The irregularity in Mariout is largely due to imperfect spikes.

[2] Field.

FERTILITY.

The variation in fertility is the most evident and the most vital of all the modifications that occur in barley. At each node of the rachis a group of three single-flowered spikelets is produced. In the 6-rowed barleys, each of these develops a separate kernel. As the groups of spikelets are placed alternately on opposite sides of the rachis the result is six columns of kernels from the base to the tip of the spike. In the 2-rowed barleys, only the central spikelet at each node is fertile, and therefore there are but two columns of grains. This reduction does not take place by the elimination of the outer spikelets but by their sterility. The median floret of each set of three accomplishes its normal development, while on either side are the small, undeveloped, infertile florets. However, the sexual organs have not disappeared. The three stamens reach an appreciable size and the ovary, though rudimentary in some ways, persists even to the plumose stigma. In one group of the 2-rowed barleys there is a still further modification of the lateral florets. In Abyssinian barleys there is a considerable number of forms in which the lateral spikelets are rudimentary; that is, they no longer contain even infertile flowers, the whole spikelet being reduced to structures that are little more than hairlike.

In the experience of the writer these well-known taxonomic divisions have proved entirely stable. The observations have included hundreds of varieties, and these varieties have been grown under such varying conditions as to stimulate monstrous developments in many structures, but in no case has there been indication of bridging over these separations. It is the opinion of the writer that the numerous instances of exceptions recorded have been misinterpreted. The one cited by Körnicke (15) was most probably a cross, as the variation of the progeny was such as is always secured by hybridization. The more common exceptions usually described are the occurrence of 3-rowed and 8-rowed freaks, and 2-rowed barleys in which some of the lateral florets are fertile. All three exceptions are probably due to the formation of adventitious spikelets. Such spikelets are common, and if several of them occur along one side of the rachis of a 2-rowed barley the result is a 3-rowed spike. If a duplication of the groups of spikelets at the nodes of one side of the rachis occurs in a 6-rowed barley, the result is nine rows, which, if imperfect in any way, are easily mistaken for eight. It is entirely possible that florets of lateral spikelets of 2-rowed varieties are sometimes fertile, but in practically all of the numerous cases that have been noted by the writer a close inspection of such grains has shown them to be adventitious, with the sterile floret also present.

Aside from the observations upon established forms, it has been the fortune of the writer to isolate a number of which there seem to be no published descriptions. These all came from Abyssinian barleys, and, as the work is not yet completed, only a general indication of the results need be given here. The group of 2-rowed barleys with rudimentary florets seems much larger than has been previously thought. They vary from the wide zeocrithonlike types to narrow nutanslike forms and through a series of colors and combinations of colors. In barleys received from the same region there is a group with a curious irregular, yet heritable, habit of floret abortion. In the ripened spike the spikelets are normal at the base and for a varying distance toward the tip. The upper portion usually reduces suddenly to a 2-rowed form. In this case the lateral spikelets are not merely sterile, but are reduced to only the outer glumes and the rachilla, the floret having disappeared entirely. The spikes are found to present these modifications even when the head first emerges from the boot. The actual time of the reduction has not been determined, but it is so early that no scar is present, indicating that the floret never started to develop.

THE EMPTY, OR OUTER, GLUMES.

The outer glumes present but two phases. They are usually narrowly lanceolate, but in rare forms are ovate lanceolate. In the latter case they generally bear moderately long awns. A few intermediates are formed by combinations in which only certain ones instead of all the normal outer glumes are replaced by ovate-lanceolate ones. In this investigation, while numerous ovate-lanceolate selections have been made, there has been nothing added to the information already at hand.

THE FLOWERING GLUMES.

Two of the variable features of the flowering glume are treated elsewhere. The toothing of the nerves is considered with the rest of the Svalof system under a later heading. The color of the glumes is taken up with the color of the other plant organs in the general discussion of pigmentation. Most of the remaining variable points of structure in the flowering glume are to be found in its terminal appendages, which are usually awns, but may be trifurcate hoods, in the nature of its base, and in its adherence or nonadherence to the pericarp.

AWNS.

The dimensions of the awns are naturally their most apparent variable features. There are marked varietal differences in both length and breadth of awns, but, unfortunately, they are so correlated with the taxonomic groups as to make them of slight use in separating nearly related strains. All the Hanna barleys have long, narrow awns; the *zeocrithon* and *hexastichum* forms have short, rather broad awns and the naked barleys excessively broad ones. In the Manchuria group there is some suggestive variation, but it needs the support of other variants to become convincing.

There is, in addition to these rather narrow variations, a still greater difference in length of awn. In these cases an abrupt and conspicuous reduction takes place. There are botanical varieties characterized by very short awns and others in which the glume is merely pointed. Derr (12) secured such a form through crossing. Such variations make a very decided separation from their long-awned relatives.

The toothing of the awn is subject to many variations, some of which are constant. The distinctions are often merely those of degree. There are forms, especially in the *hexastichum* and *zeocrithon* groups, in which the toothing is very profuse and the individual teeth very large. These characters are constant and are inherited, with no more tendency to variation than are other vegetative characters. In the Manchuria-Oderbrucker barley the teeth are numerous, but only average in size, being much smaller than the ones referred to above. The 2-rowed barleys of the Hanna type have fewer and very much smaller teeth than the Manchuria. In still other barleys the awns are smooth. In 1910 the writer isolated from a mixed Hanna barley a form in which the awn was smooth, except for a few small teeth at the tip. In 1911 two plants were secured from an English importation of a seldom-cultivated botanical variety in which the awns are absolutely smooth. Hybrids of this selection upon Manchuria and Bay Brewing sorts show the toothing to be dominant over the absence of teeth. In the second generation smooth awns again appeared. Regel (22) and others have reported a considerable number of such barleys.

Although it seems not to have been used by systematists, the rigidity of the awn has been found to be serviceable in varietal descriptions. From most barleys it is broken rather easily in thrashing, but there are some which will not thrash clean, no matter how much effort be expended. This character is commonly recognized in the California barley, but exists in Mariout, in some of the selections from Odessa, and in numerous others as well. These varieties have been grown at a large number of points and show no inconstancy in this character.

There is also a difference in the persistence of the awns. There are a few varieties that are almost deciduous. The Primus, for instance, has been observed in a great variety of locations, and it always drops a large percentage of its awns as it ripens. The loss of the awn in such varieties does not come about through the breaking of that organ, but by its being loosened from the glume. It is the tissues of the glume that give way, and lack of persistence is thus in reality a character of that organ.

In the hooded barleys the awn of the flowering glume is replaced by a trifurcate appendage. This is of evident monstrous origin and is connected with the awned class by no true intermediates. The exact nature of the appendage is not clear. In structure the parts appear to be the result of vegetative stimulation, and they are glume-like in appearance. The fact that they are three in number and that they bear rudimentary florets indicates that they are a partial repetition of the spikelets of an internode, the leafy segments being the flowering glumes. The character is absolutely constant.

THE BASE OF THE FLOWERING GLUME.

The method of the attachment of the lemma, or flowering glume, to the rachis has been shown by Atterberg (1) to be a distinguishing mark between the *erectum* and *nutans* groups. In the *nutans* group the grain (and therefore the flowering glume) is attached by a very constricted band of tissue which, when separated, leaves the proximal extremity smooth. The surface is oblique to the long axis of the grain and presents a small horseshoe-shaped depression just above the line of attachment. In the *erectum* group there is more than one variation of form, but all are centered around an attachment to the rachis that is much broader than in *nutans* and the depression is absent. When the central nerve of the dorsal glume is not too large and continued too far through the base, a transverse crease is found just above the attachment. The 6-rowed barleys are separated by the same means.

ADHERENCE OF THE FLOWERING GLUME TO THE PERICARP.

The normal form of barley is one in which the glumes are grown fast to the pericarp. There are numerous varieties in which this union does not occur. These constitute our naked barleys. Both forms are absolutely stable. The character offers no opportunity for minor distinctions, unless it be in such cases as Princess, which the Swedish Plant-Breeding Association maintains has a low weight per bushel, owing to an abnormally loose attachment of the glumes.

THE SVALOF CHARACTERS.

In 1889, Neergaard (19), of the Swedish Plant-Breeding Association at Svalof, announced the most important discovery in the classification of the lesser groups of barley that has ever been brought to the attention of the world. Not only was it of exceptional intrinsic value, but it acted as a great stimulus in the study of elementary forms and has been the cause of much of the progress that has been made in the isolation of biotypes.

Neergaard's work was based upon the careful study of the spike. He discovered that two previously unobserved variants were dependable morphological distinctions. These were the nature of the covering of the basal bristle and the toothing of the inner pair of dorsal nerves. The basal bristle, which is the continuation of the rachilla of the spikelet, is clasped within the folds of the glumes and is carried with the kernel when it is removed from the spike in the process of thrashing. The bristle is covered in some cases with long, stiff hairs; in others, with short, curly ones. The inner pair of nerves upon the dorsal surface of the grain are in some cases provided with numerous, small, translucent teeth; in others they are smooth.

The use of these two new characters gave four separations in any group, i. e., long-haired bristle and nerves without teeth, long-haired bristle and nerves with teeth, short-haired bristle and nerves without teeth, and short-haired bristle and nerves with teeth. When these separations were applied to the larger groups, *Hordeum sativum erectum*, *Hordeum sativum nutans*, and *Hordeum sativum vulgare* (*tetrastichum*), 12 smaller groups resulted.

Although this new grouping was only a small part of the Svalof observations on barley, it soon became known as the Svalof system, due no doubt to its novelty. As a new departure it has been subject to much more controversy than have most of the older and universally accepted taxonomic features. Several breeders, among whom Broili (10) is the most notable, have attacked the system and declared that, though the characters might be trustworthy at Svalof, when the plants were grown under other conditions they did not remain constant. Tschermak (13, p. 286), Blaringhem (7), and others, have supported the investigators at Svalof in the matter of the basal bristle, but have not committed themselves so completely with reference to the toothing of the nerves. Since the point of contention is the effect of soil and climate, observations in this country are of many times the natural value of those in Europe. The variation between California and Minnesota or Idaho and Virginia represents a range that is impossible to a European breeder.

Observations have been made upon some hundreds of selections representing all botanical groups. Very little variation was found in the nature of the rachilla. All observations tend to credit this character with as much stability as is usually found in taxonomic work. As would naturally be expected, the toothing of the dorsal nerves has been found to be more variable and more influenced by climate. The rachilla is the axis of the spikelet, a definite and vital portion of the fruiting body. The teeth on the dorsal nerves are of no vital significance, being mere manifestations of the epidermis. The writer feels that the Svalof position has here been injured by a defense that is too enthusiastic. The fact that variations may or may not occur in a strain is of little importance if the limits are definable. No doubt there is variation, and it is especially noticeable in the sparsely toothed varieties. A cactus under proper conditions will display leaves, yet no one will question the propriety of describing the cacti as leafless plants. They never become foliage plants, and no more do we expect a smooth-nerved Hanna selection to show the strong toothing of the Manchuria. It may at times present a few scattering teeth, but it would never become even moderately strongly toothed, and certainly there are strongly toothed sorts that are never anything else.

VARIATIONS IN THE KERNEL.

The kernel itself varies in many ways. The more definite variations not treated elsewhere are shape, dimensions, weight, and composition.

SHAPE OF KERNEL.

The shape of kernel is well established as a group distinction and is often a varietal characteristic. The 6-rowed varieties are sharply set off from the 2-rowed ones by the twisting of the lateral kernels. Even the central kernel of the 6-rowed varieties, although it is not twisted as are the lateral ones, is still of a shape different from that of the 2-rowed sorts. In the 6-rowed varieties the greatest diameter is nearer the distal end of the grain, while in the 2-rowed ones it is nearer the proximal end.

Within the groups the separations are naturally less marked. Certain Finnish and Russian barleys may readily be distinguished from the Manchuria because of their being less nearly oval in shape. The extremities of the grain are more pointed, giving a fusiform, or spindle-shaped, seed. The Goldthorpe barleys, especially such extreme types as Standwell, are readily separated from the other 2-rowed forms. The Swedish Plant-Breeding Association reports that Hannchen and Princess can be readily distinguished in bulk samples by the shape of the kernel. Most of the distinctions, however, are so dependent upon the relative proportions of the grain that it is impossible to consider shape independent of dimensions.

THE DIMENSIONS OF THE KERNEL.

The barley kernel varies in length, width, and thickness. At times one or all of these may constitute a varietal character. No other barley could be confused with the Smyrna. Its long grain is unique. It is also very doubtful whether a second strain could be found that possesses the unusual breadth of the Standwell. In all but these very extreme types the use of these variants must rest upon statistical methods.

At any place, the product of a variety in the same season is sufficiently uniform to give a decided indication of the average size of the kernel with 100 measurements. The size of the kernel is, however, but partially dependent on variety. Table VI gives a summary of measurements made upon samples of grain of three varieties of barley grown at various points in the United States. In this table the columns marked "Greatest" and "Least" have very little significance, but the averages are quite instructive. The variation is remarkably uniform. The length and the lateral and dorso-ventral diameters of Princess each differ about 0.5 of a millimeter in the averages, while the dimensions of Primus each vary 0.4 mm. and those of Chevalier II 0.2 mm. It does not necessarily follow that Princess is the most variable of the three. This variety was subjected to more extreme conditions than the other two, and in two locations the development was hardly normal.

TABLE VI.—*Dimension measurements (in millimeters) of 100 kernels of each of three varieties of barley.*

Variety and place of production.	Length.			Lateral diameter.			Dorso-ventral diameter.		
	Greatest.	Least.	Average.	Greatest.	Least.	Average.	Greatest.	Least.	Average.
Princess:									
Huntley, Mont. (irrigated)	10.0	9.0	9.3	3.8	3.3	3.6	3.0	2.2	2.7
Huntley, Mont. (dry land)	9.9	8.7	9.2	3.4	3.0	3.2	2.5	2.0	2.2
McPherson, Kans	9.6	8.8	9.2	3.7	3.1	3.3	2.9	2.2	2.5
Plainfield, Cal	10.2	9.0	9.5	4.0	3.3	3.7	2.9	2.3	2.6
Morris, Minn	9.6	8.7	9.1	3.7	3.0	3.4	2.5	2.0	2.3
Primus:									
Svalof, Sweden	10.1	9.1	9.6	4.2	3.4	3.8	3.3	2.5	2.9
St. Paul, Minn	10.4	8.7	9.6	3.9	3.4	3.7	3.0	2.5	2.8
Bonsall, Cal	9.8	9.0	9.5	3.8	3.2	3.6	3.2	2.6	2.8
Amarillo, Tex	10.0	8.9	9.6	3.7	2.9	3.4	2.6	2.2	2.5
Milwaukee, Wis	10.5	9.6	9.9	4.0	3.4	3.8	2.8	2.4	2.6
Fort Atkinson, Wis	10.4	9.0	9.8	3.9	3.4	3.7	3.0	2.4	2.8
Chevalier II:									
Warren, Minn	10.0	8.3	9.4	3.8	3.1	3.6	2.9	2.2	2.6
Flandreau, N. Dak	10.0	9.0	9.6	3.7	3.1	3.5	2.8	2.2	2.6
Erie, Pa	9.8	8.8	9.4	4.0	3.2	3.6	3.2	2.5	2.8
Plainfield, Cal	10.0	8.2	9.4	4.0	3.3	3.7	3.1	2.5	2.8
St. Paul, Minn	10.2	8.3	9.5	3.8	3.0	3.5	3.0	2.1	2.6
Milwaukee, Wis	10.4	8.4	9.6	4.0	3.2	3.6	3.0	2.3	2.7

Of the three measurements, that of length is obviously the most dependable. The actual variation is no greater, and since it is based upon a much larger figure it is relatively less. Also, the two diameters are more affected by ripening conditions than is the length and are therefore less serviceable for local distinctions. The length seems to be determined by varietal and climatic influences early in the life of the plant, while the diameters are dependent upon the quantity of starch infiltration at ripening time. This is well illustrated in the two samples of Princess from Huntley, Mont., one of which was grown by irrigation and one on dry land. The length of the kernels in the two samples was practically identical, while the diameters showed the greatest variations found within a variety.

The weakness of all grain measurements is not in the variation but in the fact that the interval between varieties is not great. The total range of averages is not large, and while many selections may be distinguished, a great many more must remain inseparable because of identical or nearly identical dimensions.

WEIGHT OF THE KERNEL.

The weight of 1,000 kernels is a determination that has been considered indispensable in the appraisement of exhibition samples, and it is also a very useful record in plant breeding. From the nature of this factor it is to be expected that it will vary with conditions and culture, but usually the variations are more or less parallel. In this investigation certain varieties have always been found relatively high and others relatively low in kernel weight, regardless of location or season. The character is, however, a varietal one and not often useful in separating related strains.

COMPOSITION OF THE KERNEL.

The varietal character of any barley, as far as composition is concerned, is subservient to climatic conditions. For example, if it is grown in California it will be much lower in nitrogen than if grown in Minnesota. The average differences in the composition of all varieties grown at two places is often greater than that between the two most extreme varieties at either place. Despite this fact, there is an actual varietal tendency. The Svanhals is reported in Sweden to be relatively high in nitrogen for a 2-rowed barley, and it is also high in this country. Analyses of samples of California feed from many States in the West and in the Plains area showed that this variety was always lower in nitrogen than other 6-rowed forms. Le Clerc and Wahl (17) found that the average protein content for Bay Brewing from all points was 10.73 per cent, while for the ordinary 6-rowed variety it was 11.86 per cent.

It is doubtful whether a factor with such wide and easily influenced limits can be made to be of assistance in the separation of strains, save in exceptional cases. It can, however, be used in the description of varieties, and may be of much importance in the selection of sorts adapted to satisfy market demands.

PIGMENTATION.

Color is one of the most easily determined characters of barley, but, unfortunately, it is also one of the most treacherous distinctions. The occurrence of pigments in certain cases and in certain tissues is undoubtedly hereditary and is transmitted unfailingly from generation to generation. In other cases the color appears intermittently or sporadically in strains and tissues ordinarily free from pigments. This erratic behavior, coupled with the fact that white, brown, black, violet, purple, amber, and blue-gray have been used in various classifications, led the writer to make a study of the pigmentation of barley. Since the colors in the seed seemed to be more numerous and less variable than in the other parts of the plant, the grain was used as the basis for the investigation.

The technic was adapted from that used by Mann (18) in his identification and location of the pigments in the cowpea. The grains were first examined by sectioning them dry. This avoided any modification such as might easily come from the action of solvents in an embedding process, or even from water if a freezing method were used. The hand sections were equally as satisfactory as those made with a microtome, as the areas in question were readily defined and the colors more easily seen in moderately thick sections than in very thin ones. The reagents most extensively employed were caustic potash, hydrochloric acid, and chloral hydrate. The sections were placed dry upon a microscope slide underneath a seven-eighths-inch cover glass, held in place by a drop of paraffin on either side. The reagents were drawn beneath the cover glass by means of blotting paper and their action watched through the microscope. Two per cent solutions of the acid and of the alkali and a saturated aqueous solution of chloral hydrate were used in these tests. If the pigment showed no change within a few minutes, the reagents were allowed to remain upon the section for some hours. In such cases, larger pieces were also placed in small vials containing 15 per cent solutions and examined at the end of 24 hours.

It soon became apparent that there were two pigments in barley. One was readily affected by the weak solutions, and from the nature of its reaction was undoubtedly anthocyanin, which occurs widely in the plant kingdom in both its red, or acid, and its blue, or alkaline, form. The other resisted even prolonged soaking in the more concentrated solutions and was probably a melaninlike substance.

The first varieties studied were those in which the adhering glumes were black. No change was effected by either the weak reagents or the prolonged soaking in concentrated solutions. The black did indeed become a brown, but this was most probably due to the distention of the pigment-containing tissues attendant upon the absorption of water. As a considerable number of varieties with black glumes were tested and as the results were uniformly the same, it would seem that a black or brown pigment in the glumes may be attributed to a melaninlike compound.

A number of Abyssinian varieties with purple glumes were sectioned and treated with the reagents. The purple color responded at once to weak solutions. It immediately became blue when treated with the alkali and became red again when the acid was applied. The chloral-hydrate test here and in all other instances was less definite than in the case with most anthocyanin deposits. Upon its application the red color faded very slowly, until the natural yellow of the glumes became apparent. The red immediately returned when acid was added. There is no reasonable doubt that the color in these barleys is due to anthocyanin.

A naked barley with a violet or purple pericarp was examined. This color was also readily demonstrated to be anthocyanin. In this instance, as in some others, the pigment was found both in the pericarp and in the aleurone layer. In the former tissue it was red and in the latter blue. When treated with acid the red was unchanged, of course, while the blue also became red, greatly intensifying the effect.

In all barleys studied the anthocyanin was always red in the pericarp and glumes and always blue in the aleurone layer. In other words, the resting condition of the protoplasm was alkaline, while the inert tissue seemed to be in an acid condition.

A new form of naked barley isolated from an Abyssinian importation gave striking testimony of the taxonomic value of the distinction between the two pigments. This selection has a dense black pericarp. It was absolutely resistant to all concentrations of reagents, showing the pigment to be melaninlike. As far as the writer can learn, there is no other naked barley of the *nutans* group in which this pigment occurs, and this botanical form has no published description.

The last variety studied was *Hordeum vulgare pallidum coerulescens*. This variety has the peculiar blue color well known upon the market in Californian, Chilean, and similar barleys. The color has been held to be variable by both grain dealers and scientists. Regel explains its lack of stability by calling it a hybrid form. Examination showed the color to be due to a deposit of anthocyanin in the aleurone layer. This layer was readily changed to red by the application of acid and was as readily made blue again by the use of alkali.

The stability of this and other forms was studied in the fields. Anthocyanin seems likely to be found in any plant and in any part of the plant. It seems to appear abnormally in cases of malnutrition and is very likely to occur in conductive tissues that are ceasing to be functional. It has, however, a normal phase in the grain. In certain naked forms its stability is unquestioned, and, to the writer's mind, its variability in *coerulescens* has been overestimated. The hybrid theory of Regel in regard to *coerulescens* becomes untenable when two pigments are admitted. If an intermediate, it could be so only between a white variety and a black one. This is evidently impossible, because a cross between a form with a melaninlike pigment and one with no pigment could not result in one characterized by the production of anthocyanin. The widespread opinion of variability is possibly due to faulty observation. The deposit is in the aleurone layer, and the color is sometimes obscured by the glume. The weathering of this organ, especially in humid areas, greatly lessens its transparency. The aleurone layer is covered by both pericarp and hulls. The color must not only be pronounced to enable one to detect it from without, but the coverings must also be passably transparent. When ripening occurs in rainy weather this is not the case, and the hulls must be removed in order to make a trustworthy determination. Maltsters often speak of the blue grains that appear after steeping—that is, when the coverings have become transparent.

There is undoubtedly a difference in the quantity of the pigment deposited from year to year. Part of this may be due to the conditions of growth and part to the conditions of ripening. This pigment, like melanin, is formed during the later stages of growth. It may be that an abbreviation of the ripening period, due to heat or drought, would result in a reduction of pigment.

The inheritance of this character has been tested by observations upon several strains isolated from various barleys. These have been grown for several years and at a number of places, and in every instance the aleurone layer has retained a decided amount of blue color. The black colors have become more nearly brown in some places but have never disappeared. Blue-gray and violet-purple colors in naked barleys are due to blue anthocyanin in the aleurone layer combined with a pigment-free pericarp in the blue-gray and with a red anthocyanin deposit in the violet. Both are unquestionably inherited.

Minor phases of anthocyanin formation are found in the foliage of the plant, in the nerves of the glume, and in the awn. A red foliage, although found more commonly in some forms than others, may ordinarily be disregarded. In most cases it indicates malnutrition of some sort. In the nerves of the dorsal flowering glume it may be more valuable as a distinction. A great many barleys show this character to some extent. Even the Hanna races possess violet or purple nerves just before ripening. None, however, develop the color to the degree that is attained by some of the Russian and Asiatic forms. In the barley nursery there are several Russian selections in which the stripes along the nerves are so broad that the grains are almost red. The same is true of the strain known as Kashgar, which was imported from the region of that name in India.

With reference to the color of the awn, an apparent anomaly was noted in 1911. In a certain selection some spikes were observed in which each awn was marked with two parallel stripes of red extending from its base to its tip, and other spikes in which the same stripes were deep purple. When examined in the laboratory, the color proved to be two bright-red stripes in the epidermis, below which were two chlorophyll-bearing parenchyma areas running the full length of the awn. As long as the chlorophyll was present the color effect was deep purple, but as soon as this disappeared it was light red.

SUMMARY.

While all lesser distinctions must be based upon the broader groups and no study of a cereal can omit its classification, the plant characters useful in taxonomic work and the ones most useful in plant breeding are far from being the same. Plant breeding is concerned with minute differences. The broad taxonomic divisions are serviceable only as groups. The problem of the nursery is not to separate a 6-rowed Manchuria from a 2-rowed Hanna barley, but to detect a variant in a plat of Manchuria.

Strains are often shown to be distinct in early growth by their rate of development. All barleys rush through the early stages very rapidly, and a selection that is one or two days earlier than a second is very dissimilar in appearance on a given date.

Leaf production is, in some ways, a varietal character. In some varieties the third leaf appears in three days after the second, while in others it occurs six days later. In the production of the fourth leaf even a greater range exists.

In some strains the first tiller appears decidedly later than the fourth leaf. In others it appears earlier. In some the tillers are all produced within a short time; in others the process is extended over several days.

The emergence of the awn is an extremely important note, as it occurs at a time in the life of the plant when such an observation is of great value. The development is usually normal at this time, as hot weather and drought have ordinarily not yet had any effect. The emergence of the awn has been found to be far more accurate and more easily obtained than the date of heading. The precocity of the strain at the time of the emergence of the awn is a heritable character.

The date of ripening is, unfortunately, often influenced by season and, while a valuable character, is less dependable than the emergence of the awns.

A comparison of the development during all stages serves to reveal many differences not apparent when each stage is taken separately.

The length of the culm is of use as a local breeding note, but the variations are not parallel when strains are planted in totally dif-

ferent areas. The diameter of the culm is not serviceable, because nearly related barleys have culms of approximately the same size. The thickness of the walls of the culm is a note with a large experimental error and therefore of questionable utility.

The degree of exsertion of the spike is sometimes a varietal character but is not often useful.

The number of culms per plant is to some extent a varietal character, but selections are so affected by season and location that it is very difficult to use. The width of the leaves is useful in group distinctions and sometimes in varietal separations. The length of the leaves is much less dependable, and is serviceable only in rather extreme types. The number of leaves varies with the groups, but usually closely related strains possess approximately the same number of leaves.

The density of the spike may easily be made the basis of many separations. Often varieties that show no other differences are widely dissimilar in density. The density of a selection varies somewhat with season and location, but the mean is always sharply defined and the fluctuations more or less parallel. In some strains all spikes conform closely to the mean; in others the range is greater. This seems to be a varietal character and is constant even when the plantings are made under widely varying climatic and soil conditions.

The established taxonomic groups based on relative fertility were found to be invariable under all extremes of American climate.

The natural varieties in the *deficiens* group of Abyssinian barleys seem more extensive than most classifications have indicated. From barleys of this same region a group with a peculiar habit of floret abortion has been isolated.

The length and the width of awns vary, but they are so correlated with other taxonomic characters that they are seldom useful in close separations.

The tenacity of the awn is frequently a varietal character unaffected by location or season.

The character of the basal bristle has been found to be stable under American conditions.

The toothing of the inner pair of dorsal nerves is much more variable, but the variation is usually within definable limits.

The length of the kernel, while influenced by climate, is a varietal character. The lateral and dorsoventral diameters of the kernel are varietal characters to some degree, but they are so influenced by conditions of growth as to become confusing in most instances.

The composition of the grain is a varietal character, but it is one dominated by climate.

There are two coloring materials in barley: One, anthocyanin, is red in its acid and blue in its alkaline condition; the other, a melaninlike compound, is black. The pigments may occur in the hulls, the pericarp, the aleurone layer, and occasionally in the starch endosperm. The resulting colors of the grain are quite complicated. White denotes the absence of all pigment; a heavy deposit of the melaninlike compound in the hulls results in black; a light deposit, brown. Anthocyanin in the hulls results in a light violet-red. In naked forms the melaninlike compound in the pericarp results in a black kernel; anthocyanin produces a violet one. The acid condition of anthocyanin in the pericarp superimposed upon the alkaline condition in the aleurone layer gives the effect of a purple color, while a blue aleurone beneath a colorless pericarp is blue-gray. White hulls over a blue aleurone cause the grain to appear bluish or bluish gray. Black hulls over a blue aleurone give, of course, a black appearance. The anthocyanin is always violet in the hulls and in the pericarp, showing that these tissues are in an acid condition, and always blue in the aleurone layer, showing an alkaline condition. The occurrence of anthocyanin in the pericarp of hull-less barleys is more significant than its production in the aleurone layer.

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BULLETIN OF THE
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No. 138

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
September 19, 1914.

COMMERCIAL TURKESTAN ALFALFA SEED.

By Edgar Brown,
Botanist in Charge of Seed Laboratory.

INTRODUCTION.

The United States does not produce enough alfalfa seed to supply the domestic demand for seeding purposes. The United States census report gives the production for the year 1909 as 15,799,680 pounds. During the year previous to July 1, 1910, 2,891,685 pounds, or a little more than one-sixth of the domestic crop, was imported. In 1913 the importation had increased to 6,000,000 pounds and the domestic production was approximately twice what it was in 1909. As imported seed is usually sold in this country on the basis of appearance without reference to the place of origin, Turkestan seed, which is the lowest priced alfalfa seed in the European markets, is the type now chiefly imported.

SOURCE OF SURPLUS ALFALFA SEED.

France, Italy, and Russian Turkestan each normally produce an excess of alfalfa seed over that required for domestic use and together furnish most of the seed entering into international trade. The French seed comes from Provence, in the lower Rhone Valley, and from Poitou, in west-central France. The provinces of Bologna and Modena, on the south side of the Po Valley, furnish most of the Italian seed. Commercial Turkestan seed comes from the southern part of Asiatic Russia, south and east of the Sea of Aral, including the provinces of Khiva, Bokhara, and Samarkand. The altitude of this region varies from nearly sea level in northern Khiva to 2,500 feet at Samarkand. The summers are hot, with an average maximum temperature for July of approximately 100° F., while the winters are cold, with an average minimum temperature for January of approximately zero. The rainfall is light and all the alfalfa culture is under irrigation. Generally speaking, the summer temperature approximates that of southwestern Arizona and southeastern Cali-

Note.—This bulletin is intended to warn American alfalfa growers to avoid the use of commercial Turkestan seed, which, though inferior to domestic-grown seed, is retailed at a higher price, making greater profits for the dealers. The bulletin tells how this cheapest of all alfalfa seeds in the European market can be identified.

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fornia, while the winter temperature approximates that of North Dakota, South Dakota, western Minnesota, and eastern Montana.

Of the three principal countries producing alfalfa seed for export, Russian Turkestan contributes the greatest part. Most of this Turkestan seed goes directly to Hamburg or to one of the other German ports, where it is cleaned and graded before being exported to the United States, South America, or other countries.

Although a surplus of Turkestan seed is constantly available on the European market, it is looked upon with disfavor, and comparatively little of it is purchased by European farmers. This discrimination results in making Turkestan seed the lowest priced seed which enters into international trade. The German price of Provence seed, as quoted in Berlin, is from 25 to 50 per cent higher than that of Turkestan, with Italian seed intermediate in price. The wholesale price of Turkestan seed in the United States is based upon the European price and is invariably lower, often 2 cents per pound less, than that of domestic seed, while the retail price of Turkestan seed in this country is usually higher than that of domestic seed. Thus, the cheapest alfalfa seed in Europe is brought to this country and is sold in competition with domestic seed, and usually at a higher price. Both the wholesale and retail seed dealers make a larger profit on Turkestan seed than on domestic seed, with the result that more and more of this seed is imported each year, until now practically all the imported seed is from that source. Over 95 per cent of the alfalfa seed received since July 1, 1913, came from Turkestan.

On the basis of the amount of alfalfa seed imported in the past nine years it seems a conservative estimate to assume that one-tenth of the 5,000,000 or more acres of alfalfa now growing in this country was planted with commercial Turkestan seed.

EUROPEAN ESTIMATE OF COMMERCIAL TURKESTAN ALFALFA.

In the alfalfa-growing regions of Europe alfalfa seed that is locally grown is generally preferred. When local seed can not be obtained, Provence or other French seed is considered best, with Italian seed second, while commercial Turkestan seed is the least desired.

The results obtained by European investigators who have tested Turkestan alfalfa in comparison with other varieties have shown it to be decidedly inferior. In most instances it was found to be the poorest variety tested, giving a hay production ranging from 24 to 80 per cent of that of the best variety in each locality. It is recognized as being slow to start into growth after the first cutting, thus reducing the hay yield from subsequent cuttings.

Gyárfás (4, 5)[1], reviewing the tests made at the Royal Hungarian Experiment Station at Magyarovar in 1909–11, found that Turkes-

[1] The figures in parentheses refer to "Literature cited" at the end of this bulletin.

tan alfalfa was less resistant to cold and drought, that its growth was slower, that its season of growth was shorter, and that it yielded less hay and was more quickly crowded out by weeds and grass than the Hungarian alfalfa with which it was compared. The results of the next year's tests showed the Turkestan to be inferior to the Hungarian alfalfa from every point of view.

Hansen (6, p. 409), after testing alfalfas of various origins in Denmark, says of the two lots of Turkestan used that they were similar and both poor, that the larger part of the annual yield was from the first cutting, the second cutting being small; and that it was especially to be noted that the growth after cutting was weak and slow, so that the stand was injured by grass and weeds.

Hiltner (7) found in a 3-years' test in Bavaria that Turkestan alfalfa gave the lowest yield of the varieties tested and only about one-half the yield of the best variety. Following these results, he says that the culture of Turkestan alfalfa can not be recommended.

In variety tests made by Lemmermann and Liebau (9, p. 407–411) at the Agricultural High School at Dahlem, Germany, Turkestan alfalfa yielded 70 per cent as much hay as German alfalfa.

Denaiffe (2), referring to a 6-years' test made by Stebler at Zurich, says that Turkestan alfalfa is short lived and not productive. The yield was approximately 70 per cent of that of Provence alfalfa and not as high as Spanish.

Todaro (10, p. 138), at the Agricultural High School at Bologna, Italy, found Turkestan alfalfa to yield about one-third as much as alfalfa from Hungary, Provence, and Argentina, and one-fourth as much as Italian. He says that in consequence of the inconsiderable value of Turkestan lucern, mixing it with home-grown lucern comes to be pure fraud.

Witte (12), testing alfalfa in Sweden, says that Turkestan, which yielded approximately three-fourths as much as Hungarian alfalfa, is the poorest variety tested in Sweden.

Of all the reports of European investigators, none have been found that speak favorably of the Turkestan seed. They are unanimous in their verdict that European seed, and locally grown seed especially, is more productive.

COMPARATIVE VALUE OF TURKESTAN ALFALFA IN THE UNITED STATES.

Turkestan alfalfa has been grown in the United States for about 15 years, and the following statements as to its value are based on comparative tests and observations made under widely varying climatic and soil conditions.

Freeman (3, p. 193) says that "where there is a sufficient supply of moisture and the winters are not extremely cold, lack of productivity renders the Turkestan variety much inferior to the ordinary sort. It has therefore proven a failure in the Central States and the States of the Middle West."

Kennedy (8, p. 29) found that none of the Turkestan strains tested in southeastern Nevada were as valuable as the domestic strains of alfalfa.

Brand and Waldron (1, p. 46), after reviewing the available experiments where Turkestan alfalfa seed was tested for hardiness, say that "it is apparent * * * that while none of the Turkestan strains in their present condition are hardy enough for the cold Northwest, several of them are promising for acclimatization by selective breeding methods."

Westgate (11, p. 37), referring to certain strains of alfalfa introduced from Turkestan by the United States Department of Agriculture, says that "Turkestan alfalfa was introduced into the United States in 1898 and has since been tried in all parts of the country. It has been found to be superior to the ordinary alfalfa in only limited sections. It is decidedly inferior in the humid sections east of the Mississippi River, but has given somewhat better results than the ordinary alfalfa in the semiarid portions of the Great Plains and in the Columbia Basin."

The results of comparative tests in the United States of commercial Turkestan with other strains of alfalfa have shown it to be decidedly inferior in most sections and of only doubtful value in the localities most favorable to it.

COMMERCIAL TURKESTAN ALFALFA NOT ADAPTED TO GENERAL USE IN THE UNITED STATES.

Commercial Turkestan alfalfa should not in any way be confused with the special strains of hardy alfalfas developed from certain introductions of alfalfa seed from Turkestan made by the United States Department of Agriculture. Some of these strains have proved hardy in the upper Mississippi Valley and are evidence that valuable varieties of alfalfas exist in Central Asia, but for the present none of these can be said to have passed the stage of being of use in experimental work in selection and breeding.

Commercial Turkestan seed of promiscuous origin is not adapted to general use in the United States. It is particularly unsuited to the humid climate of the East. It is not sufficiently hardy to warrant its general use in the upper Mississippi Valley, where hardiness is a limiting factor in alfalfa production. It is slow to recover after cutting, and gives inferior yields of hay, even when it does not suffer from drought or winterkilling. It has a tendency to be short lived, making it undesirable where alfalfa is wanted in long rotations, and it is also a poor seed producer

HOW COMMERCIAL TURKESTAN ALFALFA SEED CAN BE IDENTIFIED.

In view of the facts already set forth, it appears necessary to warn alfalfa growers to avoid the use of commercial Turkestan seed. Seed from this source has nothing to recommend it for general use in this country.

Fortunately, commercial Turkestan alfalfa seed can be identified by the presence of the seeds of Russian knapweed (*Centaurea picris*), shown in figure 1. These seeds are believed to be always present in commercial Turkestan seed and have not been found in commercial seed from other sources. Russian knapweed is a pernicious weed in the Crimea and in other parts of southern European Russia, but there is at the present time no alfalfa seed produced in these sections for export. In manner of growth, Russian knapweed is similar to quack-grass, Johnson grass, and the Canada thistle, being a perennial, spreading both by seeds and underground rootstocks. The seeds of Russian knapweed are slightly larger than those of alfalfa and can not all be removed by any practicable method of machine cleaning. Their chalky-white color makes them especially conspicuous, and their symmetrical form, being slightly wedge shaped, serves to distinguish them from the notched seed of other species of Centaurea, which often occur in Italian and other alfalfa seed. As the seeds of Russian knapweed are not usually abundant, a small trade sample should never be used to determine whether the seed is commercial Turkestan alfalfa. It may often happen that a number of small samples, such as are usually supplied by the trade, would contain none of these seeds, while an examination of the bulk will show them to be present. If any seeds of Russian knapweed occur, the alfalfa seed is wholly or in part from Turkestan.

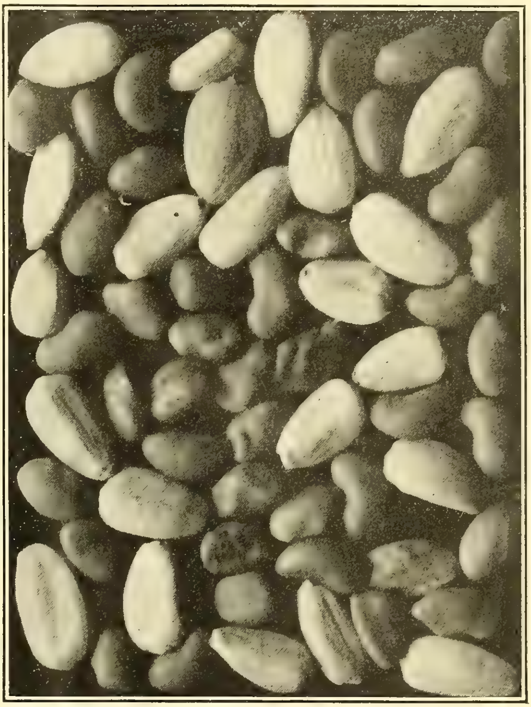

FIG. 1.—Seeds of Russian knapweed mixed with alfalfa seeds. (Magnified five diameters.) This sample shows a much larger proportion of the weed seeds (distinguished by their lighter color and their symmetrical form) than is ordinarily found in Turkestan alfalfa seed.

SUMMARY.

Russian Turkestan produces the largest supply of alfalfa seed for export.

Turkestan alfalfa seed is distributed into international trade through Germany, chiefly through the port of Hamburg.

Turkestan alfalfa has given uniformly poor results wherever tested in Europe, and none of the tests of commercial Turkestan seed in this country has given as good yields as were obtained from local seed.

Approximately one-fifth of the alfalfa seed used in the United States is imported, and practically all of this imported seed now comes from Russian Turkestan.

Commercial Turkestan is the cheapest alfalfa seed in the European market, and its wholesale price in this country is less than that of domestic-grown seed.

The retail price of Turkestan alfalfa seed in this country is usually higher than that of domestic seed; consequently, the seedsman's profit on it is greater than on domestic seed.

Commercial Turkestan alfalfa is particularly unsuited to the humid eastern portion of the United States, while it is not as hardy as other strains in the North and everywhere recovers slowly after cutting, thus reducing the hay yield. It is relatively short lived and is a poor seed producer.

Russian knapweed, a weed similar in manner of growth to quack-grass, Johnson grass, and the Canada thistle, is constantly being introduced in Turkestan alfalfa seed, and by the presence of this weed seed commercial Turkestan seed may be easily identified.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 139

Contribution from the Forest Service, Henry S. Graves, Forester.

December 4, 1914.

(PROFESSIONAL PAPER.)

NORWAY PINE IN THE LAKE STATES.[1]

By THEODORE S. WOOLSEY, Jr., *Assistant District Forester, District 3*, and HERMAN H. CHAPMAN, *Professor, Yale Forest School.*

CONTENTS.

IMPORTANCE OF NORWAY PINE IN FOREST MANAGEMENT.

Norway pine, or red pine as it is sometimes called, is a tree whose importance is certain to increase. Even now it is important commercially. From the standpoint of forest management, however, its special value lies in the fact that it makes better growth on poor soils than does its associate, white pine; it prunes itself of branches earlier, is more hardy, is freer from injury by insects or fungi, and ranges over as wide a territory. Looking into the future, therefore, when the depletion of the present stand will make it necessary to rely upon trees that can produce merchantable timber on poor, sandy soils unsuited for agriculture, Norway pine, as its good qualities become better known, will be one of the few important trees of the Northeastern and Lake States, especially for reforestation. In past reforestation work it has often been discriminated against in favor of Scotch pine, the seed of

[1] The discussion of "Growth and Yield" and the "Appendix" are the work of Prof. Chapman.

In the main this bulletin presents the results of field work conducted under the supervision of the authors, and data collected by them through correspondence. Forest Service file data were also drawn upon, as were several unpublished reports, among them one by Mr. E. M. Griffith, State forester of Wisconsin. The manuscript was read by Mr. William T. Cox, State forester of Minnesota, and by Forest Supervisors C. E. Marshall and W. B. Piper.

NOTE.—The manuscript describes the life history of the Norway pine, its requirement upon soil, moisture, and climate, its rate of growth and yield, and the best methods for its management.

As this tree is already commercially important, and this importance is certain to increase, the information presented is valuable for foresters, lumbermen, and forest owners, especially as, when the present stand of timber has been depleted and dependence must rest on trees which will produce merchantable timber on poor sandy soils unsuited for agriculture, the Norway pine will be found to be one of the few important trees of the Northwestern and Lake States.

which was easier to procure, though the tree itself had no advantages. With better methods of seed collection and storage, this drawback in the case of Norway pine can be overcome. This bulletin describes the life history of the tree, its requirements upon soil, moisture, and climate, its rate of growth and yield, and the best methods for its management.

BOTANICAL AND COMMERCIAL RANGE.

Norway pine is confined to the Northeastern and Lake States and to southern Canada. Economically, it is most important in the Lake States and in Ontario. It occurs, however, as far south as southeastern Pennsylvania and as far east as Nova Scotia, Newfoundland, and eastern Maine. Its western limit is in Minnesota and its northern at the fifty-first parallel in Manitoba.

In Minnesota its commercial range extends from Lake of the Woods to the mouth of Pigeon River, and south to Lake Pepin. In Wisconsin it occurs in 27 counties, but is abundant only in the more sandy districts. In Michigan it closely follows the range of white pine.

The supply of Norway pine in the Northeastern States is now pretty well exhausted. It was heavily logged in Maine during colonial times, and has been lumbered also in Pennsylvania and New York. In Canada it is commercially important in the Provinces of Ontario and Quebec.

Figure 1 shows its botanical and commercial range.

CLIMATE, TOPOGRAPHY, AND SOIL.

In the Lake States and Ontario, where Norway pine reaches its best development, the climate is cold in Winter and rather hot and dry in summer. The annual rainfall within this region varies from 20 to 45 inches, with from 51 to 65 per cent of sunshine. In the tree's optimum range the rainfall does not exceed 36 inches, with 60 per cent of sunshine. In Wisconsin the average annual precipitation of 31.5 inches is distributed as follows: Summer, 11.2 inches; spring, 8.3 inches; autumn, 8.1 inches, and winter, 3.9 inches. Norway pine withstands a temperature of $-50°$ F. in winter and one of $105°$ F. in summer. In some parts of the Lake States where it grows there are frosts every month of the year. The last killing frost, however, usually occurs by May 15, and the first by September 15. The foliage of the mature tree is immune to cold, though seed production is affected. Seedlings are often damaged by periodic droughts.

Throughout its range Norway pine is forced by its associates to seek the dry, sandy, or gravelly soils. It is found on dry, coarse, sand, but produces better timber on a moderately fine, fresh sand. The tree is certainly not exacting in its soil requirements, however, since a pure, fine-grained, moderately dry sand supports some of the finest stands of Norway pine in northern Minnesota. On rich, well-drained soil the tree has great possibilities, if given the start over its competitors. In its soil and moisture requirements, Norway pine is somewhat more exacting than jack pine but considerably less so than white pine, which requires some clay in the subsoil. It can not endure drought like jack pine, but grows well on sands where the better grade of jack pine is found. Mechanical analysis has shown typical jack-

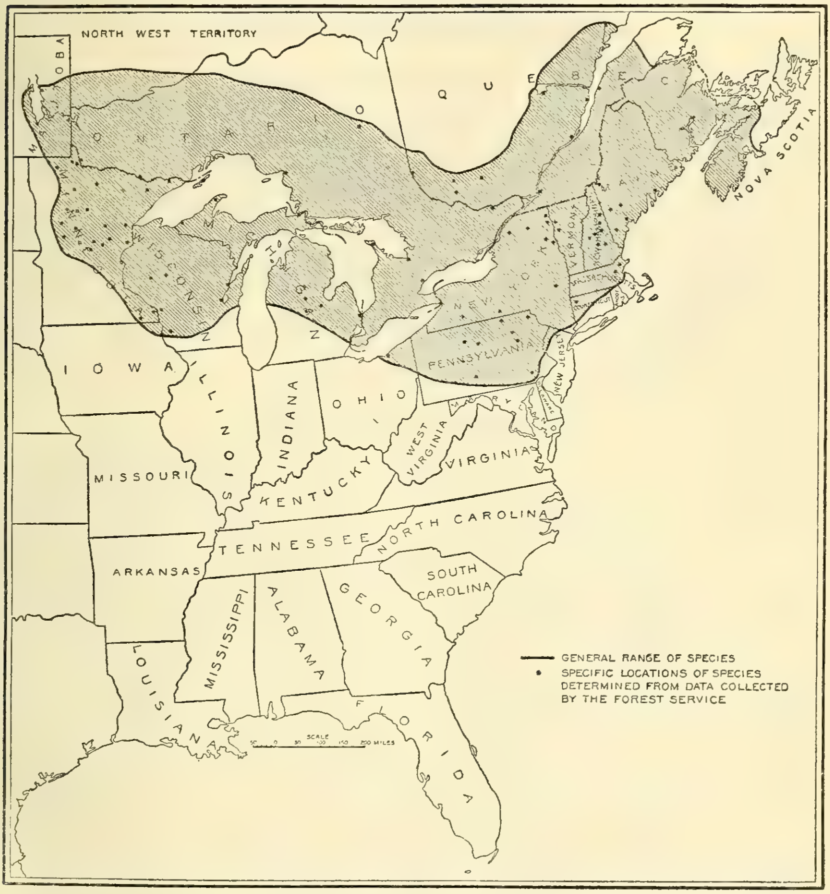


FIG. 1.—Distribution of Norway pine.

pine soil to consist of 60.6 per cent coarse sand, 30.1 per cent medium sand, 3.3 per cent fine sand, and a scattering of fine gravel, very fine sand, silt, and clay. Typical Norway-pine soil is composed of 62.9 per cent fine sand, 12 per cent medium sand, 11.5 per cent very fine sand, 6.7 per cent silt, 3.7 per cent coarse sand, 2.8 per cent clay, and 0.4 per cent fine gravel. White-pine soil contains no gravel, 43.4 per cent very fine sand, 26.1 per cent silt, 16.2 per cent fine sand, 6.4 per cent clay, and 7.9 per cent coarse and medium sand. When the virgin stands are first cut off, these sands may grow crops for a few years until the humus is exhausted. After that the necessity for expensive fertilizers makes agriculture unprofitable except with extraordinary market conditions.

Norway pine is rarely found in hilly country or in swamps, except in Cook County, Minn., where it occurs on some high ridges. It is common along lake shores.

GROSS BOTANICAL CHARACTERISTICS.

Norway pine belongs to the two-needled group of pines, the needles themselves being from 5 to 7 inches long. The bark of young trees is thin, dark, and scaly; that of mature trees is moderately thin, grayish yellow or reddish brown, in diamond-shaped plates. Owing to the characteristic appearance of the bark and the relatively high specific gravity of the wood of young trees, the latter are often locally distinguished as "pig iron" and "shellbark Norway." The cones, some 2 inches long, are brown and brownish yellow when mature. The brownish buds have rolled-back scales; the seed is held as with forceps and has light wings.

HABIT AND ROOT SYSTEM.

The bole of Norway pine is normally slender, straight, or in old age slightly bending, with but little taper. It is unusual to find a forest-grown tree with a decidedly crooked, misshapen bole. The difference between the straight, symmetrical bole of young red pine and the frequently misshapen one of white pine, the result of weevil damage, is strikingly apparent. The large tufted clumps of long needles give the crown an open appearance, in contrast to the denser crown and more delicate needles of white pine and the ragged, narrow crown of jack pine. The branches are in distinct whorls. In old age the crown becomes short and irregular. Seedlings during the first summer develop a taproot from 6 to 18 inches long. The sapling, therefore, has a strong taproot, which gives place to to stout laterals as the tree matures. Except when overmature and declining in vigor, Norway pine is remarkably windfirm.

SIZE AND LONGEVITY.

Norway pine rarely reaches a diameter of more than 33 inches breast high. The largest tree of which there is a reliable record measured 60 inches in diameter outside the bark. On the Minnesota National Forest the average run of 16-foot logs cut from a stand mostly over 200 years old scaled 15 to the thousand board feet. The average run of mature Norway pine in mixture with hardwoods, or with white pine on the better soils, is perhaps from 11 to 13 logs to the thousand board feet. In northern Minnesota the average tree in mature timber over 200 years old measured 18.7 inches in diameter. Norway pine does not grow very tall. On the sandy soil of the region a tree from 200 to 250 years old occasionally reaches a height of from 90 to 120 feet. The tallest tree recorded was 150 feet high, but the accuracy of this measurement is questionable.

The oldest tree found was 307 years old, and but few over 280 years were encountered. Norway pine, however, seems to decline in vigor after it reaches an age of from 200 to 230 years.

TOLERANCE.

For their best development Norway pine seedlings should have direct sunlight. They can not endure as much shade as those of white pine, but will grow in a moderate shade under a jack-pine stand, and exact less light than the latter species. In small, natural openings in a Norway pine stand a few white-pine trees will seed up the ground ahead of Norway. This intolerance partly accounts for the earlier and more thorough pruning of the latter. Even in pure stands on poor soil early and clean pruning is the rule. The wind also plays a part in pruning by swaying the tall, slender-boled trees, the branches of which are thus brushed off in contact with those of neighboring trees. This is especially the case when Norway pine occurs in mixture with hardwoods. In its light requirement Norway pine may be considered as halfway between "very intolerant" and "intermediate."[1] As a means of comparison, the classification in regard to demands upon light of a few other species may be given. Balsam fir is classed as very tolerant, beech tolerant, white pine intermediate, Norway pine and red oak intolerant, and tamarack and cottonwood very intolerant. The intolerance of Norway pine is indicated by the occurrence of its reproduction; under a shade density of over 0.5 as a rule it does not reproduce. It begins to reproduce abundantly when the density falls to 0.3.

REPRODUCTION.

Norway pine seedlings need some protection against extremely hot winds and drought. On the other hand, if there is too much undergrowth or shade from the parent stand the young growth will suffer. In plantations, however, it was found that Norway pine seedlings will stand sun, exposure, and weeds much better than will those of white pine.

Norway pine produces seed in abundance only at intervals of from 3 to 5 years. The seed falls in September and early October. Seed

[1] For a discussion of tolerance see Forest Service Bulletin 92, "Light in Relation to Tree Growth," by Raphael Zon and H. S. Graves.

years are local; there may be a good crop in Minnesota and a failure in Michigan or Wisconsin the same season. According to Forest Service records there have been five seed crops in Minnesota at 3-year intervals since 1898. In Wisconsin there were crops in 1890, 1893, 1897, and 1900. In Canada good seed years are said to occur not oftener than every 5 to 7 years, due possibly to the colder climate. Trees in the open have produced good cones when 25 years old, and in stands when from 50 to 60 years old. It is not known definitely when seed production begins to fail in old stands, but probably the fertility and quantity begin to fall off when the trees reach an age of 150 years. Squirrels annually destroy large quantities of seed.

The seed is disseminated by the wind and can be relied upon to restock areas at least 300 yards away, provided the soil has been bared by logging. Even after proper dissemination there is always a chance that seed will fall on heavy litter to dry out before germination or on sodded ground where it can not get a start. Seedlings do not establish themselves after fire if there is much ash on the ground. Light burning before a seed crop may often be conducive to excellent reproduction where the soil is moderately rich. On dry, pure sand even a light fire may keep out Norway and white pine and give jack pine a start. After a fire jack pine always seeds before Norway, because it produces seed each year, which are released from cones by the heat of the fire. White pine will come in first where there is partial shade, provided it is not crowded out by broadleaf trees. On areas between these two extremes of baked, parched soil, free from all growth on the one hand and ground covered with dense underbrush on the other, Norway pine reproduction will have the best chance.

However, the three pines compete with one another for the occupancy of the ground, as shown by actual measurements of reproduction on small plots in the National Forests. On the Minnesota National Forest, on an area where 5 per cent of the stand had been reserved for seed, there were 1,900 Norway and white pine seedlings per acre which had come in on exposed mineral soil rather than near the seed trees. In Hubbard County, Minn., on a plot 50 by 100 feet, there are 499 jack pine seedlings and only 481 of Norway pine, although there were two Norway pine seed trees and no jack pine within 300 feet. In a small, open stand, composed of 3 white pine and 70 Norway pine, growing on sandy soil, there were 13 white pine seedlings to every 1 of Norway pine. Near Mahtowa, Minn., young stands of Norway pine 7 and 8 years old averaged 20,855 trees to the acre, and near Barnum and Moose Lake stands about 23 years old averaged 4,699 trees to the acre. This shows that excellent reproduction of Norway pine is possible, provided soil conditions during the seed year are favorable, notwithstanding the fact that the tree is a meager seed bearer. Reproduction on the average cut-over tract is usually very deficient because of fire and excessive cutting. Aspen, paper birch, and jack pine usually crowd out the white and Norway pine. On most cut-over lands there are few Norway pine seed trees, so that reseeding will take centuries unless assisted by artificial reforestation.

SUSCEPTIBILITY TO INJURY.

Freedom from ordinary injuries constitutes the strongest recommendation in favor of Norway pine for forest management. This quality might adapt the tree to turpentining, though the short growing season would be a decided drawback.

FIRE.

Mature Norway pine may be charred at the butt by an ordinary ground fire, especially the uphill side of the tree where there is an accumulation of needles, but the burn is seldom followed by decay. Careful observations in northern Minnesota [1] indicate that young Norway pine seedlings resist fire better than either white or jack pine.

OTHER DAMAGE.

Norway has few serious enemies. In the seedling stage it seems to suffer no more from damping off than do other conifers, though the tender roots are occasionally attached by a grub as yet unidentified. It is rarely frost killed, but in the forest a prolonged drought may seriously decrease the seed crop. In the sapling and pole stage it is practically free from windfall and fungi. Mature Norway pines, when growing on well-drained soil, are rarely defective. The strong lateral root system makes the tree windfirm, though if isolated when overmature it may blow down.

THE WOOD.[2]

APPEARANCE AND STRUCTURE.

The wood of Norway pine is redder in color, in most cases slightly heavier, and invariably more resinous than that of other northeastern commercial conifers. However, before seasoning, the softer grades, cut from trees of rapid growth, are scarcely distinguishable from those of white pine. After thorough seasoning this similarity is less marked, because Norway pine is generally darker and more resinous.

The better quality Norway pine wood is soft, light, moderately strong and tough, fine, and straight grained. It is easy to work, but is not durable in contact with the soil. The best grades are cut from trees of rapid growth, on low, moist, rich soil, and exhibit very

[1] "Report on the Jack Pine Barrens of Northern Minnesota," by J. P. Wentling.

[2] Prepared by C. D. Mell, assistant dendrologist, and W. D. Brush, scientific assistant, Forest Service.

little contrast between early and late growth. Lumber cut from slow-growing trees, on dry, sandy soils, is redder in color, more resinous, and somewhat harder and more durable than the other. There is also a marked difference between the weight and quality of lumber cut from young stands and from mature timber, due to the percentage of sapwood in the former. Sargent gives the specific gravity of dry wood (unquestionably cut from mature trees) as 0.485. The sapwood of immature trees has a specific gravity of 0.9, and the heartwood of 0.6. It is this difference between sapwood and heartwood which perhaps gives rise to the term "pigiron," since second-growth Norway pine with a wide sapwood would not float. In the course of experiments by the Forest Service, under the direction of H. D. Tiemann, small blocks cut from "pigiron" floated from 2 to 9 days, while heartwood floated from 3 months to 1 year. Thus the floating ability of timber cut from young stands can be determined by computing the volume per cent of sapwood and heartwood in the logs. In mature trees the sapwood is narrow, rarely exceeding 3 inches.

In the softer grades of Norway pine the late wood of the annual rings does not contrast very sharply with the early wood, as is the case with the hard grades, or in the yellow or hard pines, of which longleaf pine is typical. Moreover, the late wood usually forms much less than one-half of the width of the annual ring. This and the slight contrast between the inner and outer part of the annual ring gives the wood a rather uniform structure and density, rendering it equal to white pine for many purposes.

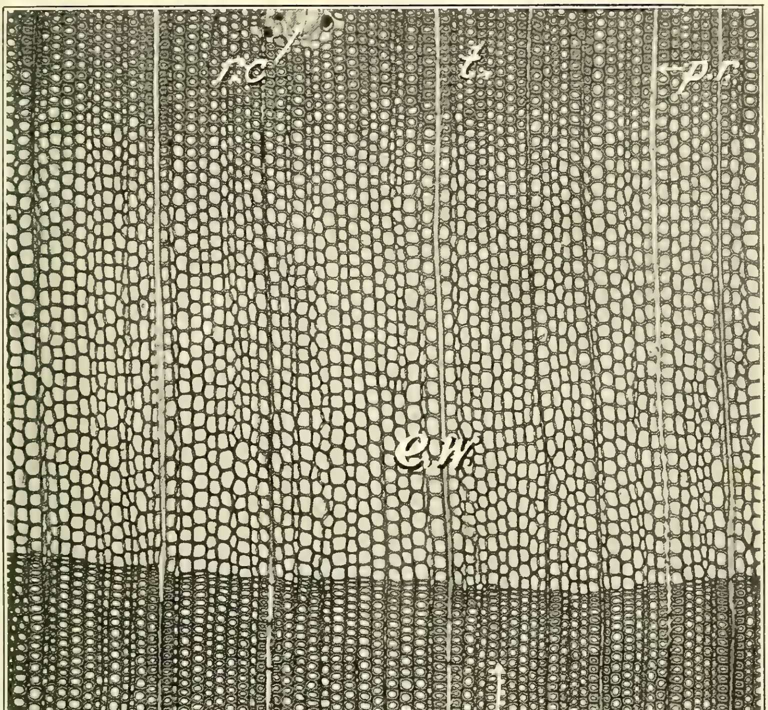
Microscopic characters which distinguish Norway pine from other pine woods with which it is likely to be confused are the conspicuous dentate projections on the inner walls of pith-ray tracheids and the large simple pits (from 1 to 2) to each longitudinal tracheid and the radial walls of the ray-parenchyma cells. The following analytical key will be of assistance to technical students in the identification of red, white, and jack pine:

Inner walls of pith-ray tracheids without dentate projections.

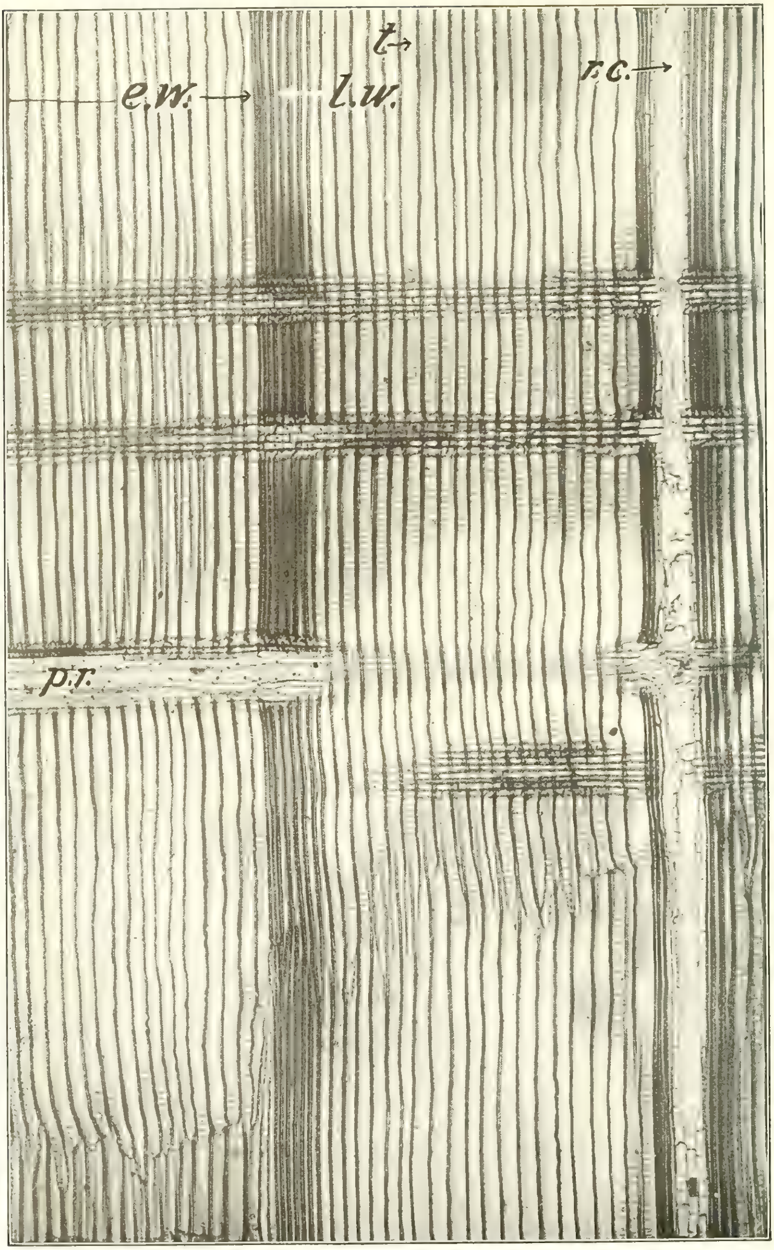
- One to 2 large simple pits to each longitudinal tracheid on the radial walls of the ray-parenchyma cells. Late wood narrow, inconspicuous; wood sparingly resinous.......................................White pine (*Pinus strobus*)

Inner walls of pith-ray tracheids with conspicuous dentate projections.

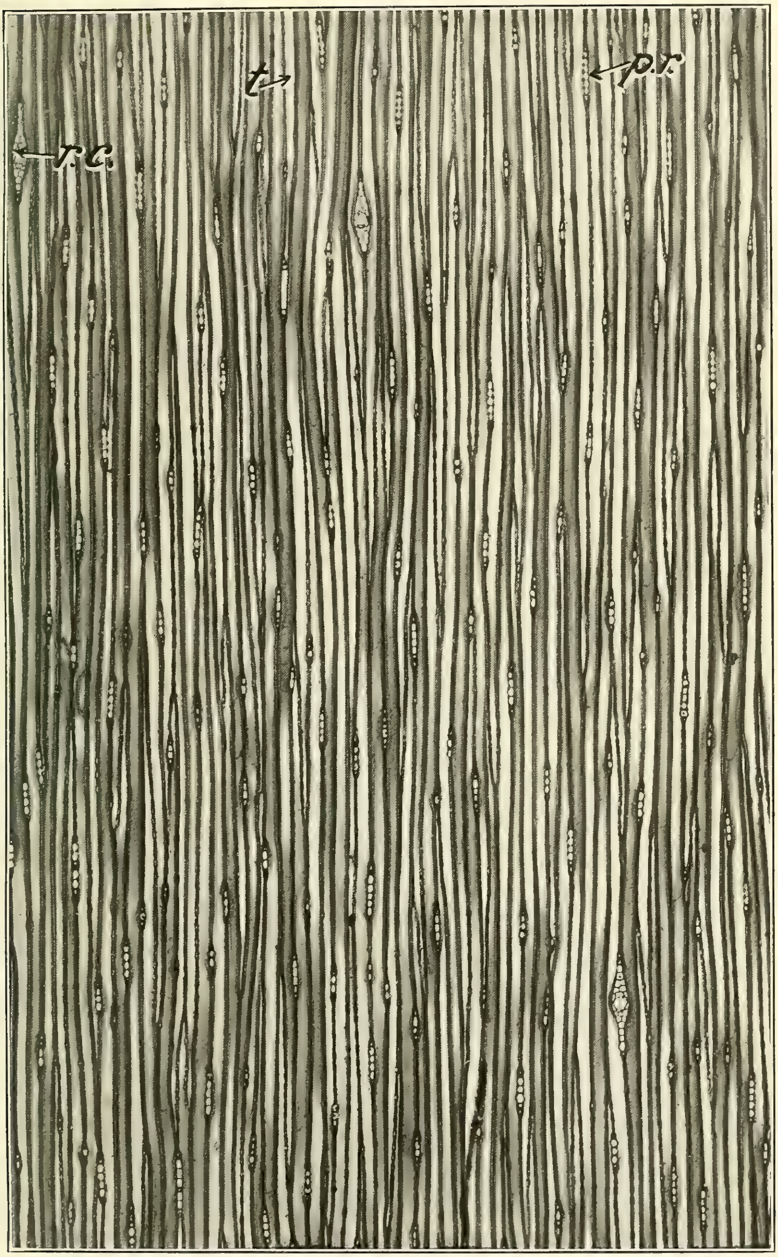
- One to 2 large simple pits to each longitudinal tracheid on the radial walls of the ray-parenchyma cells. Dentate projections regular, short. Late wood conspicuous, not sharply defined from the lighter early wood of the same annual ring. Wood usually very resinous..............Norway pine (*Pinus resinosa*)
- One to 6 (usually 3 to 6) oval, simple pits to each longitudinal tracheid on the radial walls. Dentate projections irregular, long, often branched and connecting across the cells. Late wood very conspicuous, sharply defined from the early wood. Wood moderately resinous......Jack pine (*Pinus divaricata*)



TRANSVERSE SECTION OF THE WOOD OF NORWAY PINE MAGNIFIED 50 DIAMETERS; *e. w.*, EARLY WOOD; *l. w.*, LATE WOOD; *t.*, TRACHEIDS; *p. r.*, PITH RAY; *r. c.*, RESIN CANAL.



RADIAL SECTION OF THE WOOD OF NORWAY PINE MAGNIFIED 50 DIAMETERS; *e. w.*, EARLY WOOD; *l. w.*, LATE WOOD; *t.*, TRACHEIDS; *p. r.*, PITH RAY; *r. c.*, RESIN CANAL IN PITH RAY; ALSO A LONGITUDINAL CANAL.



TANGENTIAL SECTION OF THE WOOD OF NORWAY PINE MAGNIFIED 50 DIAMETERS; *t.*, TRACHEIDS; *p. r.*, PITH RAYS; *r. c.*, RESIN CANAL IN PITH RAY.

STRENGTH.

Norway pine is stronger than white pine, but weaker than longleaf. Grade for grade, it is not quite as strong as tamarack, but experiments by the Forest Service showed thoroughly seasoned Norway pine to be slightly stronger and stiffer, when the seasoning checks in tamarack were considered. The results of the strength tests are given in Table 1.

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TABLE 1.—*Strength of green Norway pine in bending, compression, and shear.*

Section.	Span.		Number of tests.	Rings.	Moisture.	Weight per cubic foot. As tested.	Weight per cubic foot. Dry.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Modulus of resilience.	Shearing stress at rupture.
				Per inch.	*Per cent.*	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Inch=lbs. per cu. in.*	*Lbs. per sq. in.*
MAIN BENDING TESTS.												
4 by 10 inches	13 feet 6 inches	Average	49	13.6	[1] 43.8	[1] 36.3	[1] 25.2	2,550	3,975	1,189	0.52	....
4 by 12 inches		Maximum		32.4				3,915	5,625	1,700	1.03	....
6 by 12 inches		Minimum		6.7				1,600	2,810	808	.22	....
MINOR BENDING TESTS.												
2 by 2 inches	30 inches	Average	135	11.4	[1] 33.3	[1] 34.6	[1] 26.0	2,808	5,173	960	0.48	....
		Maximum		32.0				5,100	7,610	1,578	1.49	....
		Minimum		4.0				1,420	3,070	495	.18	....
COMPRESSION TESTS—LARGE PIECES.[2]												
4 by 7 inches and 6 by 7 inches	....	Average	13	10.7	[1] 45.6	[1] 31.8	[1] 21.9	2,090	2,560	1,024	....	....
		Maximum		16.7				2,725	3,180	1,375	....	....
		Minimum		6.2				1,555	2,020	722	....	....
COMPRESSION TESTS—SMALL PIECES.[3]												
2 by 2 inches	....	Average	178	11.4	Green.	....	....	....	2,504	....	....	....
		Maximum		32.0				....	4,740	....	....	....
		Minimum		4.0				....	1,400	....	....	....
SHEARING TESTS—SMALL PIECES.												
1 by 4 inches and 2 by 4 inches	....	Average	20	7.5	Green.	....	....	....	....	....	....	589
		Maximum		15.0				....	....	....	....	768
		Minimum		5.0				....	....	....	....	476

[1] Moisture determinations not completed for all tests. [2] Height of specimen, 30 inches. [3] Height of specimen, 8 inches.

PRESERVATIVE TREATMENT.

Since Norway pine is not durable in contact with the ground and when exposed to moisture, timber so placed must be treated with some preservative. The details of various methods of preservation are discussed in Forest Service Bulletins 78, 84, and 118; Circulars 80, 98, 101, 104, 111, 112, 117, 128, 132, 134, 136, 139, and 151; and Department Bulletin 13.

FOREST TYPES.

Only on moderately poor soils, usually a sand, does Norway pine grow pure. On the richer soils and on well-watered sandy flats it is found in mixture with hardwoods and white pine, and on the driest sands with jack pine. In Ontario the densest stands of Norway pine are found on pure-sand plains. Four chief types may be distinguished: (1) Norway pine knoll; (2) Norway pine flat; [1] (3) hardwood ridges; and (4) jack-pine plains.

NORWAY PINE KNOLL.

The pure sand of the knolls favors Norway pine, which is the chief, or perhaps the only, tree on such situations. The soil cover is a scattering of wintergreen, blueberry, and "ground pine," with a thin mat of needles.

NORWAY PINE FLAT.

On the sandy flats Norway pine may occasionally grow pure, but where clay is present in the soil white pine forms from 40 to 60 per cent of the stand, with a much denser ground cover. Clumps of birch may occupy the openings. On low, poorly drained ground there is usually a scattering of white spruce and occasionally a tamarack. The moist soil insures dense undergrowth.

HARDWOOD RIDGES.

On the glacial ridges, where a drift of clay covers the subsoil, the forest is chiefly broad leaved. Aspen, sugar maple, hornbeam, paper birch, yellow birch, basswood, black ash, white ash, mountain maple, with a scattering of white spruce, white pine, and Norway pine, form the stand. Often there is a pure growth of aspen, with a few paper birch, white spruce, and maple. Again, paper birch is pure with a few aspens, hornbeams, or spruces. In certain localities there is ample evidence that much of this hardwood land bore white pine of enormous size. Fire and windfall probably caused the change in the type. Often a few overmature white and Norway pines rise out of the dense understory of hardwoods. Some of the largest Norway pines are found scattered through hardwood forests. They have broad, bushy crowns, with a comparatively short, very full, well-pruned bole.

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[1] On the richer soils this type would be locally termed white pine flat.

JACK-PINE PLAINS.

Jack pine obtains possession of the driest, sterile sands through its ability to reproduce prolifically after fire and to grow rapidly during the seedling and sapling stages. Originally, it is believed, Norway pine formed at least 10 per cent of the stand on this type, but repeated fires have decreased this proportion until on some sand plains there is no Norway pine at all.

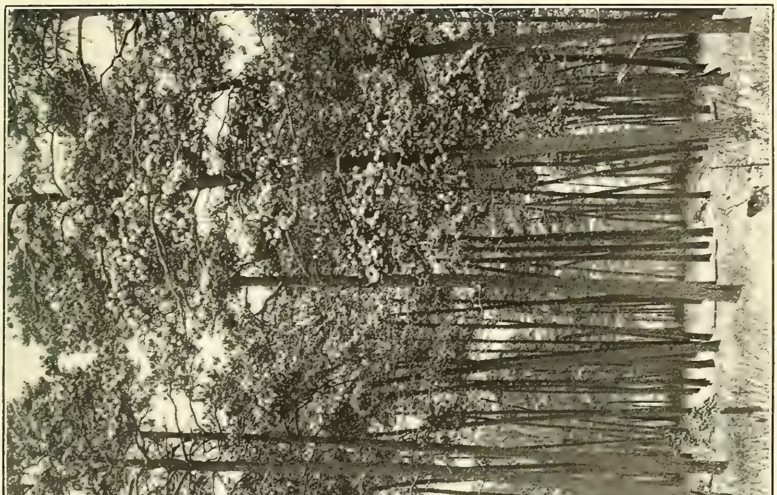
COMPETITION WITH OTHER SPECIES.

For Norway pine to succeed, the ground must be at least partially free from thick grass, briars, and weeds and not excessively dry. White pine, on the other hand, succeeds best with some cover, such as bushes, berry vines, or scattered poplar and cherry seedlings. On the richer soils the tolerance of white pine enables it to obtain a start over Norway, which is usually crowded out. On moderately dry, pure sand Norway pine drives out the white pine and hardwoods by its more rapid growth. On rich clay, suitable for agriculture, the hardwoods obtain the supremacy through their ability to seed up the soil and get a good start. As such stands become open, however, white pine, and later some Norway pine, gain a foothold. Dry, coarse sands favor jack pine, which grows faster than Norway pine at the start, but which begins to decline in vigor when from 80 to 90 years old, permitting the Norway pine to break through the crown cover and quickly occupy the available growing space.

SUPPLY AND CUT.

The total stand of all pines in the Lake States to-day probably amounts to more than 50,000,000,000 board feet. Of the 250,000,000,000 feet estimated to have been cut in the Lake States since lumbering began, Norway pine has probably furnished about 15 per cent, or about 37,000,000,000 board feet. The estimated present stand of Norway pine—17,000,000,000 feet—will probably appear too small after another decade or so, since with proper fire protection the production of second growth should materially increase the supply.

Accurate estimates of the cut of either white or Norway pine in the Lake States are impossible, because the two species are marketed together. Mr. R. S. Kellogg, secretary of the Northern Hemlock and Hardwood Manufacturers' Association, has estimated that between 1880 and 1910 Norway pine formed 25 per cent of the total cut in Michigan, 20 per cent of that in Wisconsin, and 15 per cent of that in Minnesota. These figures may be taken as conservative. In 1911, Mr. H. S. Childs, secretary of the Northern Pine Manufacturers' Association, estimated that Norway pine cut 30.4 per cent of the total production in Minnesota and Wisconsin, a conclusion reached on the



CLOSE STAND OF NORWAY PINE, CASS LAKE, CASS COUNTY, MINN.

basis of a census of 17 manufacturers in the former State and 12 in the latter. The proportion of Norway pine to the total cut of former years was no doubt small, but it has probably always formed from 10 to 20 per cent. In 1906, H. H. Chapman, professor of forestry at the Yale Forest School, wrote:

> The proportion of Norway pine in the total annual cut in Wisconsin is rapidly increasing lately at the expense of white pine, and is now about 33 per cent of the annual cut of pine for the State, excluding hemlock, while in the Wisconsin Valley the proportion reaches nearly 50 per cent. In past years Norway pine formed only from 5 to 10 per cent of the Wisconsin pine cut. In Minnesota Norway pine forms 30 per cent of the pine cut.

A further cause for uncertainty with regard to the cut of Norway pine has been introduced by the increasing cut of jack pine, some of which is being marketed as "Norway."

GRADES.

Norway pine is graded under rules agreed upon by the Northern Pine Manufacturers' Association. These are given in Table 2. The details of each grade are discussed in a booklet of rules which can be obtained upon request from the secretary of the association.

TABLE 2.—*Standard grades of Norway pine.*

Thick finishing:
- 1st, 2d, and 3d clear, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 inch.
- A select, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 inch.
- B select, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 inch.
- C select, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 inch.
- D select, $1\frac{1}{4}$, $1\frac{1}{2}$, and 2 inch.

Inch finishing:
- 1st, 2d, and 3d clear.
- A, B, C, and D select.
- D stock.
- C and better Norway.

Siding:
- A and clear.
- B, C, D, and E.

Flooring:
- A, B, C, and D flooring.
- Farmer's clear flooring.
- No. 1, No. 2, and No. 3 fencing, D. and M.

Shiplap, grooved roofing, and D. and M.:
- No. 1, No. 2, and No. 3.

Factory plank or shop common:
- No. 1, No. 2, and No. 3 shop.
- Inch shop.
- Short box.

Factory selects:
- Factory A select and better.
- Factory B and factory C select.

Thick common lumber:
- Tank stock.
- Select common.
- No. 1, No. 2, No. 3, No. 4, and No. 5 common.

Common boards:
- No. 1, No. 2, No. 3, No. 4, and No. 5.

Fencing:
- No. 1, No. 2, No. 3, and No. 4.

Dimension:
- No. 1, No. 2, and No. 3 or cull.

Lath:
- No. 1 and No. 2.

PRICES.

Norway pine has risen greatly in value during the past two decades. Virgin Norway was once purchased for less than 50 cents per thousand board feet. To-day values less than $4 per thousand board feet for good "second growth" are exceptional. Stumpage on the National Forests in Michigan is sold for as much as $12 per thousand, and will undoubtedly go still higher.

The better grades of Norway pine, when sold as such, bring less in the open market than do similar grades of white pine, but below the No. 1 grade in dimension or No. 2 in inch lumber the two species bring the same. Norway pine is seldom, if ever, quoted separately in lumber price lists. Even in high grades it is often sold indiscriminately with white pine, and so brings the same price. As a general rule, therefore, the prices quoted for white pine can be taken as those for Norway as well. Average mill-run prices for white pine in Minnesota and Wisconsin during the last quarter of 1913 were as follows:

Selects C and better	$56.00
Shop, No. 1, 8/4	48.49
Shop, No. 3, 5/4	22.87
Bevel side	24.42
Timber, No. 1, 2 inches by 4 inches by 16 feet	20.33
Boards:	
No. 2	22.83
No. 3	21.00
No. 4	16.66
Fencing, No. 2	25.36

MARKETS.

With the decrease in the supply of white pine lumber, Norway pine is certain to come more and more into demand. A glance at the list of uses given below for which Norway pine is adapted shows its commercial possibilities. In the investigation of the Wisconsin wood-using industries the Forest Service found that approximately 7,500,000 feet of Norway pine, valued at $124,000, was annually used in that State alone, of which 84 per cent was logged within the State. A similar study in Minnesota showed an annual consumption in that State of over two and one-half million dollars worth of Norway pine, costing on the average $15.74 per thousand board feet.

USES.

Norway pine is adapted for most of the uses to which white pine is put. It was first cut in Maine and Canada for shipbuilding material, such as decking, planking, spars, and masts.[1] It is used locally for bridges, though it is distinctly inferior to longleaf pine and Douglas fir for the purpose. Perhaps it is in widest demand for dimension stuff and for ordinary house construction. The lower grades and smaller sizes are consumed largely by the box trade for crates and

[1] For further details regarding early uses of Norway pine, see Forest Service Bulletin 99, "Uses of Commercial Woods in the United States: Pines," by Hu Maxwell and William L. Hall.

shipping boxes, and less frequently for shingles and water pipes. The better grades are used for farm implements, planing-mill products, furniture, car construction, panels, screens, doors and sash, and when treated with preservatives for poles, posts, and ties. The Chicago & North Western Railway is authority for the statement that Norway pine piling, where below the water and moisture line, gives excellent service, since the wood does not splinter badly under ordinary driving. During 1911 and 1912 over 20,000 pieces of piling, from 40 to 64 feet long, were sold on the Minnesota Forest at from $16 to $20 on the stump. When used for bridge piling above ground the sapwood rots quickly unless treated. Norway pine paving blocks, impregnated with 16 pounds of oil per cubic foot have given excellent results in Minneapolis.[1] While experiments with the paving blocks are still in progress, it has already been established that Norway pine, though slightly inferior to longleaf pine, is fully equal to western larch and white birch as a paving material. There is no positive record of the wood's value for pulp. The stumps yield turpentine, and are a satisfactory raw material for distillation. Other parts of the tree are not considered sufficiently resinous for the purpose.[2] A company in Michigan reports a yield of 8 gallons of turpentine and 270 pounds grade F rosin per cord of 4,000 pounds of stump wood. In Wisconsin about 61 per cent of the local output and importations of Norway pine are used for boxes and 23 per cent for sash, doors, blinds, and interior and exterior finish. In Michigan about 42 per cent goes into planing-mill supplies, and 24 per cent into boxes and crates. In Minnesota the most important uses of Norway pine are for gates and fencing, and for paving.

GROWTH AND YIELD.

HEIGHT GROWTH.

Norway pine makes an average height growth of 1 foot per year until it reaches an age between 60 and 70 years. From that time on the height growth gradually falls off, until at the age of from 100 to 110 years it practically ceases. The crown of the tree then assumes a broad flat shape.

When planted together with white pine, the height growth of Norway exceeds that of the former for the first few years by from 3 to 5 feet. This initial advantage soon disappears, however, since the white pine maintains its height growth to a greater age. Jack pine grows much faster than either Norway or white pine for the first two decades, a characteristic which in many instances enables it to over-

[1] For more detailed information, see Forest Service Circular 194, "Progress Report on Wood Paving Experiments in Minneapolis," also Municipal Engineering, Vol. XXXIV, p. 14.

[2] For further information see Forest Service Circular 114, "Wood Distillation."

top and partially or completely suppress the other pines. The height growth of Norway pine is best in full sunlight, when slightly crowded.

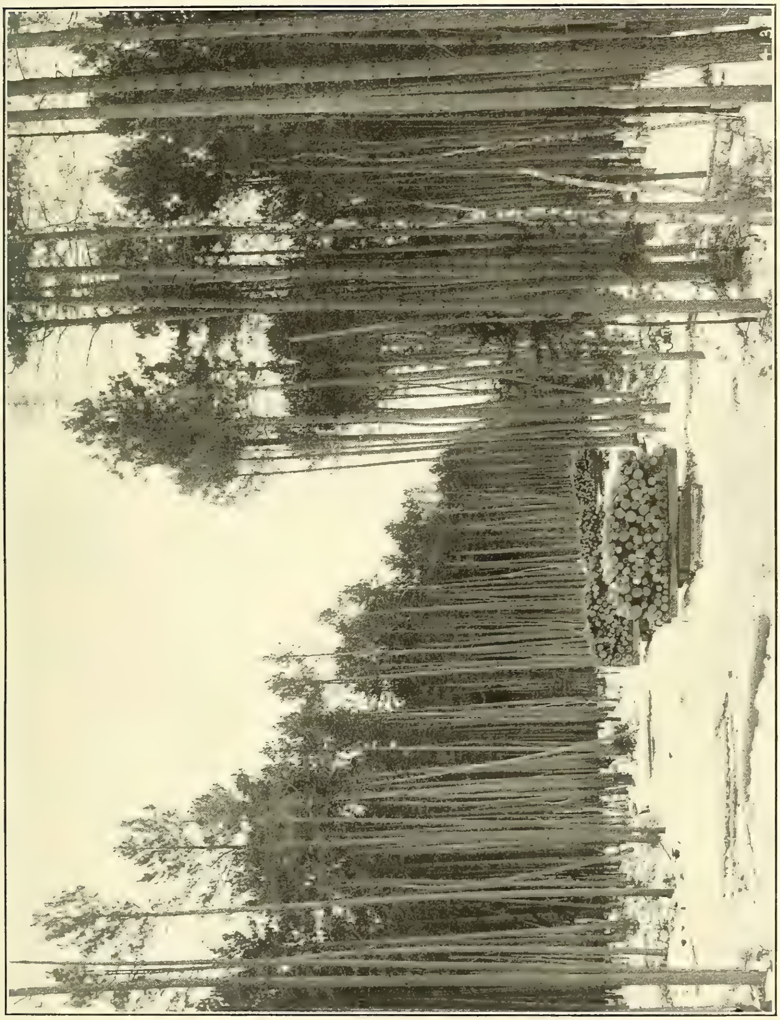
The average height growth of saplings in fairly well-stocked stands is shown in Table 3. No measurements were made of the growth in height of older trees. From the measurements of height on diameter, Table 4, and the measurements of diameter on age, Table 7, it was possible to construct a table of height growth based on age. This table is based on the assumption that diameter and height growth are roughly proportional. Thus, if the height of a tree of a given diameter is known and also the age of the diameter corresponding to the height of this tree, the age of the tree having this height is thereby determined. Table 5 has been constructed after this plan. It shows the average height of trees of different ages. Figures for minimum and maximum heights are also given. The maximum trees grew in Wisconsin in mixture with white pine and were dominant. The minimum figures are for slow-growing suppressed trees.

TABLE 3.—*Height growth of saplings in northern Minnesota.*

Age (years).	Height.	Age (years).	Height.	Age (years).	Height.	Age (years).	Height.
	Feet.		*Feet.*		*Feet.*		*Feet.*
1	0.3	8	4.9	15	15.0	22	23.0
2	.6	9	6.0	16	16.7	23	23.8
3	1.0	10	7.2	17	18.1	24	24.6
4	1.5	11	8.5	18	19.3	25	25.5
5	2.2	12	9.9	19	20.4	26	26.3
6	2.9	13	11.4	20	21.3	27	27.1
7	3.9	14	13.1	21	22.1	28	28.0

TABLE 4.—*Minimum, average, and maximum heights based on diameter, Minnesota and Wisconsin.*

Diameter breast-high (inches).	Height.			Diameter breast-high (inches).	Height.		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
	Feet.	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
1	11	12	16	18	61	88	112
2	16	20	28	19	63	90	113
3	18	27	41	20	66	91	114
4	21	34	52	21	68	92	115
5	24	41	63	22	71	94	116
6	26	47	72	23	73	95	116
7	29	53	80	24	76	96	117
8	32	58	87	25	78	97	118
9	35	63	93	26	80	99	119
10	38	67	97	27	83	100	120
11	41	71	101	28	85	101	121
12	44	74	103	29	87	103	122
13	47	77	105	30	89	104	123
14	50	80	107	31	91	105	124
15	53	82	108	32	93	106	125
16	55	85	109	33	95	108	126
17	57	87	110	34	98	109	127



FOREST OF NORWAY PINE, WITH LOADED SLEDS ON ICE ROAD, RED LAKE COUNTY, MINN.

TABLE 5.—*Minimum, average, and maximum heights based on age, Bayfield County, Wis.*

Age (years).	Height.			Age (years).	Height.		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
	Feet.	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
10	7	12	19	110	74	92	102
20	16	35	56	120	78	94	104
30	26	58	78	130	81	95	105
40	34	70	86	140	83	96	107
50	43	77	91	150	86	98	108
60	50	82	94	160	88	99	109
70	56	85	96	170	89	100	110
80	62	88	98	180	91	101	
90	67	90	99	190	93	103	
100	71	91	101	200	94	104	

Table 5 apparently indicates that the height growth of maximum trees is very rapid for 40 years and soon afterwards dwindles to almost nothing. In reality the height growth is much more gradual and continues longer than indicated in the column headed "Maximum." The most rapidly growing trees, which apparently show a height of 86 feet for 40 years, are merely trees which when 86 feet high have a diameter of 13.8 inches, this being the average height of a tree of that diameter. As a matter of fact, a tree which grew 13.8 inches in diameter in 40 years could not reach a height of 86 feet in the same time. The column containing the average figures gives a more nearly correct idea of the growth in height.

Table 4 shows the relation between diameter and height.

DIAMETER GROWTH.

The diameter growth of a tree is influenced to a very marked extent by the quality of the soil and the density of the stand. This effect is clearly shown in the following classes: (1) Dominant trees. According to their past history in the stand these may be divided into those which have survived to reach merchantable size, those which occupy a dominant position in the stand, and those which have been suppressed for about 100 years by jack pine; (2) intermediate trees; and (3) suppressed trees. The growth in diameter of these different classes of trees, with different crown development, is shown in Tables 6 to 10. Table 6 gives the best, average, and slowest growth in diameter on good soil in Bayfield County, Wis., for trees which survived to reach merchantable size.

TABLE 6.—*Minimum, average, and maximum growth in diameter, Bayfield County, Wis., on basis of age.*

[Based on 139 stumps from 108 to 202 years old.]

Age (years).	Diameter breast-high (inches).			Age (years).	Diameter breast-high (inches).		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
10	0.2	0.6	1.3	110	9.3	17.9	25.2
20	1.0	2.8	5.4	120	10.3	18.9	26.2
30	1.9	5.7	10.3	130	11.3	19.8	27.1
40	2.7	8.0	13.8	140	12.4	20.8	28.0
50	3.7	9.9	16.6	150	13.5	21.7	28.7
60	4.6	11.7	18.8	160	14.6	22.7	29.5
70	5.5	13.2	20.5	170	15.7	23.7	30.3
80	6.5	14.6	21.9	180	16.9	24.6	30.9
90	7.4	15.9	23.1	190	18.0	25.5	31.7
100	8.3	16.9	24.2	200	19.2	26.5	32.4

Table 7 shows the diameter growth of trees which are now occupying a dominant position in the stand. Figures in the column headed "Maximum" are for trees which have grown practically in the open for their entire life. The column headed "Average" shows trees which have been somewhat crowded, but which from the start have dominated the remaining timber in height growth. The "minimum" is for trees which have been suppressed by jack pine. The growth in both diameter and height of such Norway pines is stunted. In 80 years the trees have reached a diameter of but 4.3 inches, as contrasted with 19.2 inches in the case of open-grown trees. At this age jack pine dies out, and by 100 years has entirely disappeared from these even-aged stands. The surviving Norway pines, freed from competition and with plenty of crown space, develop good crowns and take the position of intermediate or dominant trees. Only their record of diameter growth remains to show the former existence of the jack pine in mixture. Had these trees grown in pure stands, they would have been killed in competition.

TABLE 7.—*Minimum, average, and maximum diameter growth of dominant trees on basis of age, Cass and Itasca Counties, Minn.*

[Based on 739 stumps from 27 to 303 years old.]

Age (years).	Diameter breast-high (inches).			Age (years).	Diameter breast-high (inches).		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
10	....	0.8	2.7	110	6.8	14.7	22.1
20	0.4	2.8	6.8	120	7.6	15.5	22.8
30	.8	4.9	10.1	130	8.4	16.1	23.5
40	1.3	6.6	12.6	140	9.1	16.7	24.1
50	2.0	8.2	14.6	150	9.8	17.3	24.7
60	2.7	9.6	16.4	160	10.4	17.8	25.2
70	3.5	10.9	17.9	170	10.9	18.4	25.7
80	4.3	12.0	19.2	180	11.3	18.9	26.3
90	5.2	13.0	20.3	190	11.8	19.5	26.7
100	6.0	13.9	21.3	200	12.1	20.0	27.2

Table 8 shows the diameter growth of intermediate trees on situations typical of the sandy plains of low agricultural value.

TABLE 8.—*Minimum, average, and maximum diameter growth of intermediate trees on the basis of age, Cass and Itasca Counties, Minn.*

[Based on 760 stump counts.]

Age (years).	Diameter breast-high (inches).			Age (years).	Diameter breast-high (inches).		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
10	0.4	0.9	2.3	110	6.6	13.5	21.7
20	.9	2.7	6.0	120	7.2	14.2	22.5
30	1.4	4.6	9.3	130	7.7	14.9	23.1
40	2.0	6.3	12.0	140	8.2	15.5	23.6
50	2.6	7.8	14.2	150	8.7	16.1	24.1
60	3.3	9.1	16.0	160	9.1	16.7	24.6
70	3.9	10.3	17.5	170	9.5	17.2	25.0
80	4.6	11.3	18.9	180	9.9	17.7	25.4
90	5.3	12.1	20.0	190	10.3	18.3	25.7
100	5.9	12.9	20.9	200	10.7	18.9	26.0

Table 9 shows the growth of suppressed trees.

TABLE 9.—*Minimum, average, and maximum diameter growth of suppressed trees on basis of age, Cass and Itasca Counties, Minn.*

[Based on 164 stumps, 51 to 152 years old.]

Age (years).	Diameter breast-high (inches).			Age (years).	Diameter breast-high (inches).		
	Minimum.	Average.	Maximum.		Minimum.	Average.	Maximum.
10	....	0.5	1.3	90	5.3	9.5	14.8
20	0.5	1.8	3.9	100	6.0	10.1	15.5
30	1.1	3.2	6.4	110	6.7	10.7	16.1
40	1.7	4.5	8.7	120	7.2	11.3	16.8
50	2.4	5.8	10.6	130	7.7	11.8	17.4
60	3.1	7.0	12.0	140	8.1	12.3	18.0
70	3.9	8.0	13.1	150	8.5	12.8	18.6
80	4.6	8.8	13.9				

The demand of Norway pine for light, which prevents it from growing under hardwoods, white pine, or underbrush, is brought out in the growth tables. When growing with any other species except jack pine it must remain dominant by means of rapid growth or be killed by suppression in the course of time. Jack pine has such a light crown that in mixture with it Norway pine can survive a period of extended suppression and ultimately develop a fair crown growth. The better the soil the closer will be the competition between these two species. On very poor soils Norway pine in mixture with jack pine sometimes lives to an advanced age as mere stunted poles from 10 to 20 feet high and from 1 to 8 inches in diameter.

VOLUME GROWTH.

Growth in volume of Norway pine (Table 10) is derived from tables of growth in diameter and height at different ages, used in connection with a table in volumes for trees of different diameters and heights. The table indicates that Norway pine grows in volume at a uniform rate to an advanced age.

TABLE 10.—*Growth in volume, on basis of age, of average dominant trees, Cass County, Minn.*

Age (years).	Diameter.	Height.	Volume.	Scribner rule.	Periodic growth for 10-year periods.		Mean annual growth.	
	Inches.	*Feet.*	*Cubic feet.*	*Board feet.*	*Cubic feet.*	*Board feet.*	*Cubic feet.*	*Board feet.*
10	0.8	8						
20	2.8	21						
30	4.9	35	2.3				0.77	
40	6.6	47	5.3		3.0		.133	
50	8.2	58	10.1	27	4.8		.202	0.54
60	9.6	66	15.8	57	5.7	30	.263	.96
70	10.9	72	21.1	90	5.3	33	.301	1.29
80	12.0	76	27.4	128	6.3	38	.343	1.60
90	13.0	80	34.0	160	6.6	32	.355	1.77
100	13.9	83	40.6	193	6.6	33	.406	1.93
110	14.7	85	46.3	228	5.7	35	.421	2.08
120	15.5	87	53.8	263	6.5	35	.448	2.19
130	16.1	88	59.0	286	5.2	33	.454	2.20
140	16.7	89	63.6	314	4.6	28	.454	2.25
150	17.3	90	69.4	345	5.8	31	.463	2.30
160	17.8	91	74.4	374	5.0	29	.465	2.34
170	18.4	91	79.3	405	4.9	31	.465	2.39
180	18.9	92	84.4	437	5.1	32	.469	2.43
190	19.5	92	89.3	470	4.9	33	.470	2.47
200	20.0	93	94.6	505	5.3	35	.473	2.52

YIELD.

The growth in diameter, height, and volume of individual Norway pine trees is of little aid in determining the yield per acre. Yields of stands of different ages are best found by actual measurements of stands of the age to be recorded. The yield of even-aged stands is then determined by multiplying the volume of the average tree by the number of trees on the area. The sample plots upon which Table 11 is based were located in Cass and Itasca Counties, Minn. The plots selected for measurement were completely stocked with pine. A mature and fully stocked Norway pine stand forms a practically complete crown cover. The crowns themselves are not dense nor is the shade deep, though it is usually sufficient to exclude from the dry and sandy forest floor practically all underbrush, leaving only a carpet of needles. At the age of 150 years, however, the stand begins to thin out, and by 200 years the canopy will be broken, with many blanks caused by the death of trees. The yield per acre at this time is actually less than at an earlier age.

The method followed in constructing Table 11 was to plot the yield of each sample plot on cross-section paper, on the basis of age. The space between the maximum and minimum curves was then divided into three parts, representing good, medium, and poor yields. These coincide roughly with the three qualities of soils upon which the plots were taken. A curve was then drawn through the center of each space representing the qualities, from which the yields for each age were read. In applying this table it should be remembered that the figures represent a theoretically perfect stand. Actual yields on

FIG. 1.—NORWAY PINE POLES AND SEEDLINGS, ROSCOMMON COUNTY, MICH.

FIG. 2.—NORWAY PINE ON THE MINNESOTA NATIONAL FOREST.

sand barrens where there are small openings may, even in the case of plantations, be from three-fourths to one-fourth of these amounts. Table 11 is based on 85 sample plots from 40 to 200 years old.

TABLE 11.—*Yield per acre of fully stocked even-aged stands according to three quality classes.*

Age (years).	Yield per acre.		
	Quality I.	Quality II.	Quality III.
	Board ft.	*Board ft.*	*Board ft.*
40	4,100	2,000	------
50	9,400	6,100	2,800
60	15,100	10,200	5,300
70	20,900	14,300	7,900
80	26,500	18,600	10,700
90	32,300	22,900	13,700
100	38,500	27,400	16,900
110	44,700	32,000	20,100
120	50,800	36,700	23,100
130	56,800	41,200	25,800
140	60,500	43,900	27,900
150	62,300	45,700	29,500
160	63,300	46,900	30,600
170	63,700	47,500	31,100
180	63,700	47,700	31,300
190	63,000	47,300	31,300
200	61,800	46,500	31,000

The mean annual growth in board feet culminates on all the qualities of site at about 140 years. There is a slight further increase in volume until 170 years on Quality I, and to 180 years on Qualities II and III, but the mean annual growth per acre falls off, and soon the stand itself begins to lose in volume from windfalls, old age, and fire. The maximum mean annual yield on good soils hardly exceeds 400 per year, and on Quality III sites 200 feet. These yields are for natural Norway pine sites, whose quality is at best much below that of soils occupied by white pine and hardwoods. Since Norway pine will grow on any well-drained soil, if started in full sunlight, yields from plantations, even when unthinned, on the richer soils may amount to from 500 to 800 board feet per acre per year. Since Norway pine can form fully stocked stands only under ideal conditions of light and moisture, which are seldom met with in nature, the average stand per acre of pine, either Norway or white, actually comes nearer to being 5,000 or 10,000 feet, instead of the 40,000 or 60,000 feet yielded by fully stocked areas.

The openings in ordinary stands of Norway pine are occupied by poplar, birch, and scrub oaks, although none of these species do as well as Norway pine on sandy soils. Even if these inferior species could be utilized, nothing like the returns can be secured as from fully stocked stands of Norway pine. It is safe to say that with complete stocking the average production of large areas can be increased fivefold.

The number of trees on fully stocked areas depends in part on the width and shape of the crown. Table 12 gives an idea of the average width of crowns of trees of different diameters.

TABLE 12.—*The crown width of dominant trees on basis of diameter breast-high, Itasca County, Minn.*

[Based on 134 measurements.]

Diameter breast-high (inches).	Width of crown (feet).	Diameter breast-high (inches).	Width of crown (feet).
3	4	13	15
4	5	14	15
5	7	15	16
6	8	16	16
7	9	17	16
8	11	18	16
9	12	19	16
10	13	20	17
11	13	21	17
12	14		

The crowns of Norway pine trees are remarkably narrow compared with those of southern and western pines, which makes possible a larger number of trees per acre. An idea of the possible approximate yields which may be obtained under management is given in Tables 13 and 14. It can be assumed that with frequent thinnings the trees remaining in the stand will grow at the average rate of dominant trees and will have the width of crown indicated in Table 12. Assuming that the average volume of these trees will be that shown in Table 10, it is necessary only to know the average number of trees per acre in order to ascertain roughly the yield of such stands at a specified age.

The diameter of the average crown was squared in finding the number of such trees that could stand on an acre. Since crowns are circular, this introduced a factor of safety amounting to a reduction of 22 per cent of the number of trees which might otherwise be computed as having growing space, and gives a crown density of 78 per cent instead of 100 per cent.

TABLE 13.—*Yields per acre of dominant trees, calculated from diameter growth, average crown space, and number of trees per acre at different ages.*

Diameter breast-high (inches).	Age (years).	Volume of tree.	Trees per acre from curve, based on crown space.	Yields per acre.
		Board feet.	*Number.*	*Board feet.*
8	49	23	302	8,280
9	56	45	266	13,590
10	63	67	241	17,822
11	71	94	221	22,654
12	80	128	206	28,288
13	90	160	193	32,960
14	101	197	183	38,021
15	114	242	175	44,286
16	128	289	168	50,575
17	145	329	163	55,272
18	163	383	158	62,429
19	182	444	154	70,152
20	200	505	151	77,770

Column 2 of Table 13, which shows the age of trees of each diameter, was taken from Table 7, using the average figures of growth in the middle column of dominant trees. Much larger yields would have been indicated had the left-hand column been made the basis of the calculation.

Column 3 was obtained from Table 10, volume growth of Norway pine, Table 7, middle column, for diameter growth of dominant trees, and from Table 4, average height based on diameter of dominant trees.

Column 4 was obtained by squaring the crowns of trees of all diameter classes, computing the number of trees per acre for each class by dividing 43,560 by the square of the diameter of the crown, a density factor of 0.78 per cent, and then plotting the results and evening off by a curve for each diameter class.

Column 5 was obtained by multiplying column 3 by column 4.

Table 14 shows by decades the yields given in Table 13.

TABLE 14.—*Theoretical yield per acre of fully stocked stands, Quality I.*

Age (years).	Yields (board feet).	Age (years).	Yields (board feet).
50	8,400	130	50,400
60	14,600	140	54,000
70	22,000	150	57,600
80	27,600	160	61,000
90	33,000	170	64,000
100	37,700	180	66,900
110	42,300	190	69,500
120	46,500	200	72,000

These theoretical yields agree with those found by actual measurements of fully stocked stands on first quality sites. The actual yields slightly exceed those shown in Table 14, notably for the ages from 110 to 160 years. At 170 years the actual yields fall off rapidly, while the yields computed from crown space continue to increase even after the results are reduced by a curve. These facts indicate, first, that the rate of growth used in the calculation is actually attained by the greater number of trees forming a Norway pine stand on good soil, and, second, that the density of the crowns of such stands is greater than 0.78, which is the assumed factor of density obtained by squaring the crowns which are normally round. Finally, the divergence of yields for 170 years clearly indicates that at this age the natural stands begin to deteriorate and do not maintain the closed canopy. The decrease in the number of trees per acre resulting from this process of deterioration lowers the yield from then on. Individual Norway pines will live to be 300 years old, but plots much over 200 years old are composed either of the remnants of much denser stands or of the survivors of a struggle with jack pine.

It is an interesting fact that a Norway pine tree which has been stunted for from 30 to 50 years, if it recovers, adds that period to its normal life. This behavior has also been noticed in the case of tamarack and the giant sequoias of California. Table 15 gives some interesting figures of increment for 8 sample plots measured in pole stands. The volumes are computed to a 2-inch merchantable diameter on the basis of the average tree for each diameter class.

TABLE 15.[1]— *Yield per acre of fully stocked sapling and pole stands on good-quality soil.*

	Serial No. of plot.							
	1	2	3	4	5	6	7	8
	Location.							
	Re-lease.	Grand Rapids.	Men-ahga.	Black-berry.	Clo-quet.	Itasca Park.	Shev-lin.	Itasca Park.
	Soil.							
	Sand.	Sandy loam.	Sandy clay.	Sandy clay.	Sandy clay.	Sandy clay.	Sandy clay.	Sandy clay.
Age of stand....................years..	13	15	15	17	27	27	41	79
Average diameter breast-high. inches..	2	3½	3½	4	5	5	4½	8½
Average total height.............feet..	10½	22½	16½	20	29	21	40	69
Total number of trees per acre.........	1,720	2,616	713	778	1,512	874	616	524
Volume at present.........cubic feet..	145	1,235	272	548	1,368	1,085	990	5,534
Volume 5 years ago.............do....	....	121	55	74	647	548	455	4,620
Total increment last 5 years...........	....	1,114	217	474	721	537	535	919
Annual increment last 5 years.........	....	223	44	95	140	107	107	184
Average annual increment..cubic ft..	11	82	18	32	50	40	24	73
Volume at present.............cords..	2	17.3	3.8	7.7	19.1	15.2	14	79.5
Volume 5 years ago.............do....	....	1.6	0.8	1.2	9.1	7.6	6.3	64.6
Total increment last 5 years...........	....	15.5	3	6.5	10	7.6	7.7	14.9
Annual increment last 5 years.........	....	....	....	1.3	2	1.5	1.5	3
Average annual increment....cords..	0.15	1.3	0.25	½	0.7	0.56	0.34	1
Volume at present........board feet..	1,015	8,645	1,912	3,840	9,581	7,595	6,934	39,735
Volume 5 years ago.............do....	....	849	383	525	4,530	3,838	3,187	32,332
Total increment last 5 years...........	....	7,798	1,519	3,318	5,047	3,757	3,745	7,403
Annual increment last 5 years.........	....	1,560	302	665	980	751	749	1,580
Average annual increment..board ft..	77	643	126	224	350	281	169	503

The figures in the table would indicate a remarkably rapid growth. On the whole, however, it is clear that upon poor soils, and with the comparatively cool and short growing season, rapid growth and heavy yields can not be expected at an early age. The returns from either plantations or natural stands inside of 40 years will be negligible, yet in the end the species not only exceeds in the capacity for timber production any other species adapted to sandy soils in the North, but equals and probably exceeds in yield per acre the Scotch pine grown on similar soils in Europe. If such growth is possible in the more northern latitudes, and on the sandier soils, it should produce yields equal to or exceeding those of white pine at the southern

[1] Furnished by William T. Cox, State forester of Minnesota.

limits of its range and on the richer soils occupied by hardwoods. This fact, when taken in connection with its immunity from the white-pine weevil and freedom from other forms of insect or fungous attacks, should give Norway pine an important place in future forest management.

There is a tendency to use Scotch pine on soils suitable for Norway pine. The height growth of the Scotch pine exceeds that of the Norway for a few years, but the future development of the former species as a timber tree in America can not be predicted. Much Scotch pine seed is collected from stunted trees which can not produce sizes of commercial value. In Norway pine, on the other hand, the forester has a tree whose growth and development is absolutely certain, and therefore should be depended upon in large commercial plantations on poor soils.

MANAGEMENT.

RESULTS UNDER THE MORRIS ACT.

The only systematic attempt at management of Norway pine on a considerable scale has been made on the Minnesota National Forest, under the Morris Act of June 27, 1902. This act as passed provided that 5 per cent of the total volume of standing timber be left in seed trees. In 1908 an amendment to the bill doubled this percentage. When 5 per cent of the volume was left, there were from 0.2 to 1.5 seed trees per average acre, or about 0.6 seed trees per acre for the area as a whole. Cutting was begun in 1904, but the areas were burned over the same year, so the results from cutting 95 per cent of a Norway pine stand can not be predicted with certainty. Young growth has come in well on two areas where light fire, which cleared out the underbrush, was followed by a good seed crop. Owing to the rather open stand, averaging about 6,000 board feet per acre, considerable ground cover existed before the logging. Taken as a whole, the natural reproduction is not a success, because not enough seed fell immediately after logging, when the bared soil was in the best condition to receive it. What young growth there is has sprung up as the result of the chance combination of a good seed year with a suitable condition of the soil. Where conditions have been favorable, however, the results are unexpectedly good.

Before condemning the Morris Act because better results have not been obtained, one must bear in mind that as a forerunner of forest management in Minnesota it was necessarily a compromise between the clear cutting of the old-time lumberman and the ideal conservative fellings of the forester.

ROTATION.

The time at which Norway pine should be cut must be determined in each individual case. To grow sawtimber from 20 to 24 inches in diameter takes on the average Norway pine soil from 132 to 173 years. The average annual growth culminates at about 140 years on all sites, and consequently the rotation which would give the greatest volume production would be one of 140 years. If timber is cut when too young or too old the full productive capacity of the soil is not utilized, especially if the timber is cut clear. When natural reproduction is sought, particularly with the shelterwood system or from clear cutting, the stand should be felled if possible while the trees are producing seed prolifically, i. e., between 80 and 130 years.

Financial returns.—A long rotation means a larger growing stock or forest capital; and in compound interest calculations the interest on this standing timber more than counterbalances the sale value of the additional lumber produced. To illustrate this principle, according to Table 11 a Norway pine stand on Quality II soil[1] yields 10,200 board feet after 60 years, 18,600 after 80, 27,400 after 100, and 36,700 after 120 years. Table 16 shows the estimated returns on money invested in Norway pine stands when cut after 60, 80, 100, and 120 years. Compound interest has been figured at 4 per cent on an initial cost of $15 for land and young growth; taxes and fire protection at 4 cents per acre per year; and stumpage at $20, a very conservative figure, for the years 1973, 1993, and 2017.

TABLE 16.—*Revenue derived from the conservative management of Norway pine.*

Length rotation (years).	Yield from thinnings.	Final yield per acre.	$15 capital at 4 per cent compound interest.	Approximation of final yield per cent on original investment.
60	Estimated thinnings will pay cost of taxes and fire protection	$204.00	$157.79	4½—
80		372.00	345.74	4 +
100		548.00	757.57	3½+
120		734.00	1,659.94	3¼

Any forecast of future returns necessarily involves some elements of uncertainty. What will be the taxes, fire loss, or unforeseen injuries? Will natural reproduction be wholly or partially successful, or a total failure? What will be the stumpage price? At what figure should the land and timber be capitalized? It is certain that in 1950 Norway pine in the United States will bring at least as high a stumpage price as good Scotch pine in France and Germany brings now—from $12 to $24 per thousand board feet—probably 30 to 100 per cent more, since it now nets from $10 to $12 on the stump. But even with such an increase, the returns from forest investments extending over long periods of time are certain to be small as compared with returns from short-term investments.

[1] All calculations are based on Norway pine growing on sandy soil, because this is the soil to which the tree is naturally adapted.

CLEANING OR WEEDING.

To produce timber of high quality it is essential in most cases to tend the stand practically from the start. One of the main cultural operations is to clean or weed the young stand of undesirable trees. While such an operation may be permissible from a financial standpoint in a mixed hardwood forest, it would scarcely be justified in the case of Norway pine. To clean or weed the young Norway pine stands will entail an expense of from $2 to $4 per acre. Two dollars at 5 per cent compound interest amounts to $697.82 for a rotation of 120 years, and few operators could afford this expenditure. Where the owner maintains a protective force the rangers may make systematic weedings. For example, if jack pine is temporarily suppressing the Norway pine, the ranger can top the jack pine and lessen the struggle for light. Norway pine seedlings under aspen or underbrush can be liberated. If this weeding can be done in connection with other duties, even at a small additional expense, it is certainly worth while. In Minnesota, for example, there are thousands of acres of natural forests of Norway pine, from 10 to 30 years old, which deserve attention from the owners, and which it would be profitable to hold in view of the increasing demand for small mine timbers.

THINNINGS.

The removal of undesirable or competing trees from a stand is called thinning. This reduces the loss which ordinarily takes place in the struggle for light. The silvicultural value of thinnings in Norway pine can not be questioned, although they are not of the same vital importance as in a mixed forest. In a widely spaced plantation thinnings would probably not be needed before the twentieth or thirtieth year, but will be necessary after that. Timely thinnings are important in securing natural reproduction, since they result in a final stand of trees with well-developed crowns, thus insuring abundant production of seed. Moreover, every lumberman would prefer to cut 88 20-inch boles, rather than 338 13-inch,[1] because wide lumber brings better prices than narrow boards. Under present conditions thinnings on a large scale are justified only when the sale of the products at least pays the cost. The owner of a small area of timber can improve his stand without expense by selecting the small poles needed for farm construction from dense groups of Norway pine, instead of adopting the possibly more convenient procedure of cutting a portion of his woodlot clear. Thinnings in pine stands should begin early, and be made lightly and often. In a dense Norway pine stand the first thinning should be made when the trees are from 20 to 30 years old, removing from 10 to 15 per cent of

[1] See Table 11 for yield data on unthinned stands on Quality II soil.

the stand. After that, they should be repeated every 7 or 10 years. In practice, however, this can rarely be carried out, because of the present lack of market for small saplings and the prohibitive cost of logging scattered trees. Thinnings in young pine stands should not be heavy or the height growth will be impaired. The trees will not prune so well, and the soil will not be sufficiently shaded toward the end of the rotation to prevent weeds from getting a foothold and endangering reproduction. Heavy thinnings, moreover, are likely to result in windfall, as was well illustrated in the case of the thinned stand of Norway and white pine on the Grand Marais Lighthouse Reservation a few years ago. The winds off Lake Superior are very heavy at times. Many of the trees left standing on the lighthouse reservation lean badly and appear to have their roots loosened. In this case the thinning was probably deferred too long and then made too heavy.

IMPROVEMENT CUTTINGS.

In mature and overmature stands where, as in the case of parks, the aim is not so much to secure young growth as to maintain the present stand, loss would be avoided if systematic improvement cuttings are made at intervals of from 15 to 25 years. The Norway pine trees removed should be those with straggling and light-green foliage, stag-headed, or clearly so overmature that they will not survive until the next cutting. It would be better even to cut a few healthy trees in clumps, in order to increase the amount to be logged per acre, than not to cut at all. When an overmature forest is cut systematically, it is possible to clear up the occasional windfalls, which are bound to occur in old age.

MANNER OF CUTTING.

In any partial cut of the stand the trees to be removed should be marked beforehand, in order to insure that the thinning will be carried out as planned. The method usually followed is to blaze or stamp the roots and bole of the trees to be cut. Close utilization of the material marked is even more important. The owner should see to it that stumps are cut low (from 12 to 16 inches, depending on the size of the timber), the tops utilized to the full merchantable limit (in the Lake States usually 6 inches), and that logs partially defective are removed, even if they contain only from 20 to 25 per cent of merchantable material. It is, of course, necessary to use great care not to damage reproduction which is to form the second crop. Roads, skidding trails, skidways, and the cutting of seed trees should be designed with this in view.

NATURAL REPRODUCTION.

The aim should always be to secure a second crop by natural seeding of the ground by the trees in the original stand. This can be insured in most cases by proper methods of cutting. Artificial sowing or planting, because of the initial cost [1] and because of low stumpage prices, should be resorted to only when natural reproduction fails. Even after reasonably successful reproduction takes place there will be fail places or blanks. Where the stand is open and overmature, forestation may be the only certain means of securing a new crop of Norway pine. Where sowing or planting is impracticable, the forest soil of the Lake States will, if protected from fire, still restock naturally, though with some such species as aspen or birch. These, while not as valuable as Norway pine, bring—in Maine, for example—from $3 to $10 an acre. They also have the advantage of rapid growth and ease of reproduction.

There are several methods of cutting Norway pine to secure natural reproduction, although no one has been tried out long enough to establish it as superior to any other. These methods are (1) shelterwood system, (2) group selection system, (3) clear cutting and (4) leaving seed trees. No matter which of these systems is followed, it must, in virgin stands, assume the character of a heavy improvement cutting.

Shelterwood system.—The shelterwood system of cutting—i. e., the removal of the stand in two successive cuttings—has been suggested as the ideal method of securing reproduction of Norway pine.[2] This system, however, would probably be better adapted to white pine than to Norway, because the former reproduces better under a partial shade. If applied to Norway pine, the parent stand should be removed before the seedlings suffer from suppression. If reproduction came in within a year after the first cutting, the parent stand could safely be removed from 4 to 7 years later. Until fire protection is more certain it would, perhaps, be better to leave scattered seed trees even after the second or final cutting, until the new crop reaches the sapling or pole stage. This would have its disadvantages, of course, on account of the additional cost of logging and the unavoidable damage to the young growth in cutting. Another alternative would be not to cut these "safety seed trees," but to leave them for increased growth during the entire rotation. With the shelterwood system it is important to keep close check on the progress of reproduction after the first cutting. The owner should not only guard against the suppression of the seedlings, but he should also prevent the soil from becoming so covered with brush and weeds

[1] Mr. William T. Cox, State forester of Minnesota, states that planting has been carried on successfully in parts of Minnesota for from $3.50 to $6 per acre.

[2] "Results of cuttings on the Minnesota National Forest under the Morris Act of 1902," Proceedings of the Society of American Foresters, p. 104, Raphael Zon.

that even forestation is made impossible through the prohibitive expense of clearing the soil. It is often practicable to assist reproduction by partial sowing or planting within a few years after cutting, before the soil becomes choked with weeds.

Group selection system.—Cutting Norway pine in irregular selected groups of from 2 to 10 trees may be advisable: (1) Where for æsthetic or protective purposes a mature stand must be maintained; or (2) where the fire danger is very acute and continuous areas of even-aged stands, such as would result from the shelter-wood system, must be avoided. The selection method of cutting is always more costly for the lumberman, and invariably results in considerable damage to the young growth. Theoretically not more than one-fourth to one-third of the stand should be cut at any one time, but in practice the lumberman may be compelled to take out one-half or more and wait a longer time between cuttings. There will always be danger of weeds unless the cutting can be made closely to coincide with good seed years, followed by favorable climatic conditions to insure immediate seeding. In a large operation, where cutting must be done every year, this would obviously be impracticable.

Clear cutting.—Clear cutting in strips or blocks would reduce the cost of logging, but it has the danger of opening the soil to weeds, and hence should be tried only if it can be done during or immediately following a good seed year; otherwise, planting may be necessary. The portion of the stand uncut should be north or west, as well as to the windward of the area to be restocked, in order that the ground may be kept as moist as possible. If there is not successful restocking within a few years, planting should be resorted to, where it can be done at a reasonable expense, before the ground has a chance to become choked with weeds and brush.

Seed trees.—The plan of leaving scattered seed trees has on the whole proved unsatisfactory. This system is really a compromise; it is neither clear cutting nor partial cutting, for a few seed trees per acre are insufficient fully to seed up the ground. As generally practiced, from 3 to 10 seed trees are left per acre, the more the better so far as the future reproduction is concerned. If logging can always be done at the time of a good seed crop satisfactory results may be obtained, since the soil after being stirred up by hauling and skidding offers a good germinating bed. With a mature stand windfall and sun scald are likely. About one-fourth of the seed trees on the Minnesota Forest have blown down. Yet owners may prefer to secure a very partial crop of the original species by this method on account of the small amount of merchantable timber which has to be left. The seed trees could be held over a rotation to yield lumber of large size as a provision against loss of the second growth by fire, or cut when no longer needed for purposes of seeding.

ARTIFICIAL REPRODUCTION.

Where natural reproduction fails, or where the land has been denuded, sowing and planting is the only way to secure a new timber crop. The greatest drawback to the use of Norway pine for artificial reforestation is the scarcity and high cost of the seed and the slightly lower stumpage price as compared with white pine. Norway pine, however, has advantages which white pine does not possess. It will grow better on sandy soil; it is hardier and less subject to natural injuries; it prunes itself earlier, and on poor soils produces more wood. Scotch pine is often recommended in preference to Norway, because the seed is cheaper and the plants are fully as hardy.

Opinion among foresters concerning the relative merits of Scotch and Norway pine for planting in the Lake States is somewhat divided. Up to the present the consensus of opinion has usually been in favor of Scotch pine, especially in southern Minnesota, on account of its alleged greater hardiness. If planted on a large scale for forest purposes, however, Norway pine has given good results. The fact that it is a native species gives a greater assurance of safety than would the planting of Scotch pine, of which there are as yet no mature forests in this country.

Sowing of Norway pine on the whole has not been successful in the past, and planting has been found the better method. Measurements of Norway pine in New England show the average growth to be greater than that of white pine. On sand, containing varying proportions of loam, 40,758 white pine, 30 years old, averaged 26.6 feet in height and 3.7 inches in diameter, while 40,538 Norway pine of the same age averaged 35.4 feet in height and 5.9 inches in diameter. On richer soil, 1,758 white pine, 27 years old, averaged 43.5 feet in height and 5.18 inches in diameter, while 19 Norway pine were on the average 48 feet high and 6.6 inches in diameter.[1]

Although the seed usually begins to fall after the first week in October, it should be collected in late August, September, or early October. The date when it matures varies, of course, with the weather conditions from year to year. The cost of collecting it has been from $2 to $3.06 a pound and higher. Regular seed dealers ask from $4 to $12 a pound for small lots. According to the Forest Service, a bushel of cones will average 1 pound of seed. A pound contains from 55,000 to 70,000 individual seeds, with an average germination per cent of 89. In the Georgian Bay region, forty-fifth parallel of latitude, Norway pine seed was found by Zavitz to average only 0.26 of a pound to the bushel and 52,000 seed to the pound. After cleaning, germination tests in the greenhouse gave 94 per cent.

A great deal of original work has been done in the collection and extraction of Norway pine seed by Kennety at the Cloquet Experi-

[1] Measurements made by H. B. Kempton.

ment Station, in Minnesota. Two methods of seed collecting have been tried out at the experiment station. One was to follow the logging crew and gather the cones as the trees were felled. The other was to collect the cones from squirrel hordes. The latter method was found to be by far the best. Thus, when collecting the cones from felled trees from 1 to 2 bushels was the average per man per day; from 1 to 4 bushels was the average collected from squirrel hordes. The largest caches of Norway pine found contained 1 bushel, while caches consisting of jack pine and Norway pine cones often held 2 bushels. The average number of seed from cones was found to be 37, of which 23 were good and 14 bad.

In general it was found that temperatures from 130° to 140° were the ones at which the seed could be extracted easiest with the highest percentage of germination. While for all temperatures used in the test the mean per cent of germination was 70.8, for 130° to 140° the per cent was 78.5. The lower germination per cent for temperatures of less than 130° is accounted for by the fact that at that temperature only the smaller and less fertile seed are released. In Table 17 is given the length of time necessary for Norway pine to crack and open at different temperatures.

TABLE 17.—*Length of time necessary for Norway pine cones to crack and open at different temperatures.*

Temperature.	Cracking.	General opening.	Not open.
°	*H. m.*	*H. m.*	*Per cent.*
125	1 20	4 35	12
130	1 15	4 15	14
135	1 30	4 0	14
140	45	3 45	8
145	40	2 30	8
150	40	2 22	4
155	50	2 25	6
160	45	2 30	2
165	40	2 15	....
170	35	2 20	2
175	15	2 0	....
200	15	1 30	....

SOWING.

Sowing is best done when the ground is free from weeds after logging. If the seed averages 55,000 to the pound, with a germinating per cent of 90, broadcasting would require about 5 pounds per acre. With the seed costing $4.50 a pound, sowing broadcast under these circumstances would be absolutely prohibitive. In any event, broadcasting will rarely be successful unless the soil is harrowed and raked clear of weeds, though this would not be necessary on soil cleared by fire directly after logging. It may often be practicable to supplement natural regeneration by broadcasting on a soil bared by logging when there is no seed crop.

Sowing in seed spots is cheaper. With spots 2 feet square and 8 feet apart and with 40 seed to the spot a little over a pound per acre would be sufficient. If the seed spots were spaced 6 by 6 feet, the total number of seed needed per acre would be 48,400, a little less than a pound. Seed-spot sowing should not be attempted without proper preparation of the ground, and often some kind of a brush cover will be necessary to prevent the seedlings from being dried out after germination. Mr. J. F. Kendrick, of South Orleans, Mass., secured excellent results on a pure sand by the following method:

The owner at one time attempted to farm this soil, and the year previous to starting the plantation rye was sown on the area, while during the year preceding that a crop of corn was produced. The plantation was started simply by dropping seed in the corn hills after making a small hole with a dibble. The spacing was about 4 by 4 feet. After 35 years the dominant trees were 7–8 inches diameter breast-high and 38–40 feet tall, in excellent condition, were clearing themselves well, and apparently growing vigorously.

PLANTING.

Norway pine should be planted pure or with some more tolerant species of slower growth. Planting in the early spring is preferable to that in the summer or fall. Transplants are better than seedlings, but on good soil the latter should succeed. Ordinarily it will be necessary to raise stock in the nursery, preferably near the planting site, if the planting is on a large scale. Occasionally it may be possible to transplant seedlings growing in the forest, but these give less certain results than nursery grown stock, although success with wild stock at very low cost has been reported from the Minnesota National Forest.

BRUSH DISPOSAL.

Protection of stands from fire is obviously the first step in forest management. In 1911 the loss from forest fires in the Lake States totaled $3,368,000, most of it in the pineries. As a fire-protection measure the disposal of slash [1] is of great importance. Most of the great fires in the Lake States assumed the character of conflagrations by being able to feed upon the débris left after logging. In Norway pine stands, piling and burning the brush is a prudent and essential insurance against fire. The brush is piled and burned in winter as the cutting proceeds. The cost varies from 10 to 35 cents per thousand board feet logged. On the Minnesota National Forest the average cost has been about 16 or 19 cents. Where the timber is scattering, and the fire risk proportionately small, it is usually sufficient to clear and burn fire lines intersecting and around the cut-over areas. These lines should rarely be less than 150 feet in width.

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[1] Under the Minnesota forest law the State forester is given authority to enforce the proper disposal of débris after logging.

APPENDIX.

VOLUME TABLES.

The tables which follow are based on volume analyses taken in Minnesota and Wisconsin, chiefly under the supervision of E. S. Bruce, expert lumberman. The board-foot volumes were calculated by the Scribner Rule, decimal C. In these tables no allowance has been made for defect, which must be estimated in the forest. The top cutting limit used was 6 inches inside bark.

Table 18 gives the volume in board feet for trees of all diameters, and for 16-foot logs and half lengths or 8 foot differences in merchantable height. The extremely large number of trees upon which the table is based (4,282 trees) makes its contents very reliable. The average stump height of the trees analyzed was 2 feet; the top diameter inside bark 6 inches. Usually 0.3 of a foot was allowed for trimming.

TABLE 18.—*Volume of red vine in board feet on basis of diameter, merchantable length in 16-foot logs.*

Diameter breast-high (inches).	Number of 16-foot logs.												
	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7
	Volume (board feet).												
8	20	30	40	53									
9	20	34	48	63	77								
10	20	41	57	73	89	100							
11	20	42	62	83	100	120	140						
12	20	52	74	96	120	140	160	190					
13	20	56	83	110	130	160	180	210	240				
14	20	63	96	120	150	180	210	240	270				
15		71	110	140	170	200	230	270	300	340			
16		78	120	150	190	230	260	300	340	380			
17			130	170	210	250	300	340	390	430	480		
18			140	190	230	280	330	380	440	490	550		
19				200	260	320	380	430	490	550	620	680	
20				220	290	350	420	490	550	620	680	750	820
21					310	390	470	540	610	680	750	820	880
22					340	430	520	600	680	750	820	890	950
23					380	480	570	660	740	820	890	960	1,030
24					420	530	630	730	820	900	970	1,040	1,110
25						600	700	790	890	980	1,060	1,130	1,200
26						660	760	860	960	1,060	1,140	1,230	1,310
27						720	830	940	1,040	1,140	1,240	1,330	1,430
28						790	900	1,010	1,120	1,230	1,350	1,450	1,560
29							960	1,080	1,200	1,330	1,450	1,580	1,700
30							1,030	1,160	1,300	1,430	1,570	1,710	1,850
31							1,100	1,240	1,390	1,530	1,690	1,840	2,000
32								1,330	1,490	1,650	1,820	1,980	2,140
33								1,420	1,590	1,770	1,950	2,130	2,300
34								1,520	1,710	1,900	2,090	2,280	2,480

The use of total heights instead of merchantable height is possible with a species as regular in form and as free from heavy top branches as is the Norway pine. Where this is done, the error arising from failure to employ the top diameters used in timber estimating, can not affect the results beyond the amount of the difference in the used volume or waste in the tops. Total height is a more accurate basis for estimating volumes than arbitrary merchantable heights for all species which have a regular form and are utilized closely in the tops. Table 19 gives the volumes of Norway pine in board feet classified by 10-foot differences in height, based on the 4,282 trees measured for Table 18.

TABLE 19.—*Volume of Norway pine, in board feet, on basis of diameter, total height in feet.*

Diameter breast-high (inches).	Average for all heights.	Height of tree (feet).									
		30	40	50	60	70	80	90	100	110	120
	Volume (board feet).										
8	24	10	13	17	26	34	46	53	65		
9	43	14	20	28	39	51	64	77	92		
10	66	20	28	40	53	68	86	100	120		
11	90		38	53	69	87	110	130	150		
12	120		48	67	86	110	130	150	180	210	
13	150		60	81	100	130	160	180	210	240	
14	190		70	96	120	160	190	210	250	280	
15	230			110	150	180	220	250	290	320	
16	270			130	170	210	250	290	330	360	390
17	320			140	190	240	290	330	370	410	440
18	370			160	220	280	330	380	420	460	500
19	430				260	320	380	430	480	520	560
20	490				290	360	430	490	540	590	630
21	560					400	480	550	610	670	710
22	640					450	540	620	690	750	800
23	720					500	600	680	760	830	890
24	810					550	660	760	850	920	990
25	910					600	720	840	940	1,020	1,090
26	1,010					660	790	920	1,030	1,120	1,200
27	1,120						860	1,000	1,120	1,220	1,310
28	1,240						940	1,090	1,220	1,330	1,430
29	1,360						1,020	1,170	1,320	1,440	1,560
30	1,480						1,090	1,260	1,420	1,560	1,700
31	1,610							1,360	1,530	1,690	1,850
32	1,760							1,460	1,640	1,820	2,000
33	1,910							1,550	1,750	1,960	2,160
34	2,070							1,650	1,870	2,100	2,320

The cubic volume, without bark, for trees up to 20 inches in diameter, is given in Table 20, which is based on 303 trees. Table 21 is the same except that the bark has been included.

TABLE 20.—*Volume of peeled Norway pine, in cubic feet, on basis of diameter, total height in feet.*

Diameter (inches).	Height of tree (feet).						
	40	50	60	70	80	90	100
	Peeled volume (cubic feet).						
5	2.7	3.3	4.2				
6	3.8	4.8	5.8				
7	5.0	6.3	7.8	9.0			
8	6.5	8.2	10.1	11.9	13.9		
9	8.1	10.2	12.6	15.0	17.5	19.8	
10	9.9	12.6	15.3	18.2	21.0	24.0	27.0
11		15.2	18.3	21.0	25.0	29.0	32.0
12		18.2	21.0	25.0	29.0	34.0	38.0
13		21.0	25.0	29.0	34.0	39.0	45.0
14			29.0	33.0	39.0	46.0	52.0
15				37.0	44.0	52.0	60.0
16					51.0	60.0	68.0
17					57.0	67.0	77.0
18					64.0	75.0	86.0
19					71.0	83.0	94.0
20					79.0	91.0	103.0

TABLE 21.—*Volume of Norway pine with bark, in cubic feet, on basis of diameter, total height in feet.*

[Calculated from form factors of 306 Trees.]

Diameter breast-high (inches).	Height (feet). 40	50	60	70	80	90	100	110	Form factor.
	Volume (cubic feet).								
5	3.0	3.7	4.4	...	...	...	...	...	0.542
6	4.2	5.3	6.4	7.4	...	...	...	...	.540
7	5.8	7.2	8.6	10.1	11.5	...	...	...	.538
8	7.5	9.4	11.2	13.1	15.0	16.8	...	...	.536
9	9.4	11.8	14.2	16.5	18.9	21.0	24.0	...	.534
10	11.6	14.5	17.4	20.0	23.0	26.0	29.0	...	.533
11	14.0	17.5	21.0	25.0	28.0	32.0	35.0	39.0	.531
12	16.7	21.0	25.0	29.0	33.0	37.0	42.0	46.0	.530
13	19.5	24.0	29.0	34.0	39.0	44.0	49.0	54.0	.529
14	23.0	28.0	34.0	40.0	45.0	51.0	56.0	62.0	.528
15	26.0	32.0	39.0	45.0	52.0	58.0	65.0	71.0	.527
16	...	37.0	44.0	51.0	59.0	66.0	73.0	81.0	.526
17	...	41.0	50.0	58.0	66.0	74.0	83.0	91.0	.525
18	...	46.0	56.0	65.0	74.0	83.0	93.0	102.0	.524
19	...	...	62.0	72.0	82.0	93.0	103.0	113.0	.523
20	...	...	68.0	80.0	91.0	102.0	114.0	125.0	.522
21	...	...	75.0	88.0	100.0	113.0	126.0	138.0	.522
22	...	...	...	96.0	110.0	124.0	138.0	151.0	.521
23	...	...	...	105.0	120.0	135.0	150.0	165.0	.520
24	...	...	...	114.0	130.0	147.0	163.0	179.0	.519

By a comparison of Table 20 and Table 22 which follows, and by referring to the study of specific gravity, page 8, it is possible to determine approximately what sizes of trees can be driven without danger of expensive loss through sinkers.

TABLE 22.—*Volume of Norway pine sapwood, in cubic feet, on basis of diameter, total height in feet.*

Diameter breast-high (inches).	Total height of tree (feet). 40	50	60	70	80	90	100	110
	Volume of sapwood (cubic feet).							
5	2.3	2.6	3.0	...	...	...	...	...
6	3.2	3.9	4.5	...	...	...	...	...
7	4.2	5.3	6.1	6.5	...	...	...	...
8	5.2	6.8	8.0	8.6	8.8	...	...	...
9	6.4	8.5	10.2	11.1	11.6	...	...	...
10	7.8	10.4	12.4	13.7	14.5	15.4	16.3	...
11	9.3	12.3	14.7	16.4	17.6	12.5	19.6	...
12	10.8	14.2	16.9	19.0	21.0	22.0	23.0	24
13	...	...	19.2	21.0	23.0	25.0	26.0	27
14	...	...	21.0	24.0	26.0	28.0	29.0	31
15	...	...	...	26.0	28.0	30.0	32.0	34
16	...	...	...	28.0	31.0	33.0	35.0	38
17	...	...	...	...	33.0	35.0	38.0	40
18	...	...	...	...	34.0	37.0	40.0	43
19	...	...	...	...	36.0	39.0	42.0	44
20	...	...	...	...	37.0	40.0	43.0	46

Table 22 was computed from the form factors for Norway pine. The form factor is the ratio between the volume of the tree and that of a cylinder with the same total height and diameter at 4½ feet from the ground. Trees of the same diameter and height may vary in form and volume considerably. Those trees which most closely approach cylindrical form contain the greatest volume and have the largest form factors. Old trees, with short crowns and long clear boles, which have grown in dense stands, have the fullest form, while young, rapidly growing, open-grown trees with short boles and long crowns will have the least volume for their diameter and height. Yet saplings grown in crowded stands may have a very high form factor, as may be seen in Table 23, which gives the factors for Norway pine of different heights and diameters and an average form factor for all heights on the basis of diameter; 306 trees were measured for this table.

TABLE 23.—*Form factors of Norway pine, on basis of volume in cubic feet, based on diameter and total height in feet.*

Diameter breast-high (inches).	Total height of tree (feet).							
	40	50	60	70	80	90	100	All heights.
	Form factor.							
5	0.567	0.576	0.584					0.542
6	.553	.562	.569	0.576				.540
7	.541	.549	.556	.561				.538
8	.529	.538	.544	.549	0.557			.536
9	.519	.527	.534	.539	.547	0.555		.534
10	.510	.519	.527	.532	.540	.548	0.553	.533
11	.502	.511	.520	.526	.534	.542	.549	.531
12	.495	.505	.514	.521	.530	.538	.546	.530
13	.489	.499	.509	.517	.526	.535	.543	.529
14		.495	.505	.513	.523	.532	.540	.528
15		.491	.502	.510	.521	.529	.537	.527
16			.499	.507	.517	.526	.534	.526
17				.505	.514	.523	.531	.525
18				.503	.512	.520	.529	.524
19				.501	.509	.518	.527	.523
20					.507	.515	.524	.522
21					.504	.513	.522	.522
22					.502	.511	.520	.521

Converting factors by which cubic volumes may be expressed in equivalent board-feet contents, are shown in Table 24 for trees from 8 to 20 inches and 80 feet high. This was obtained by dividing the values in Table 21.

TABLE 24.—*Board feet—cubic-foot converting factors for Norway pine trees 80 feet in height on basis of diameter.*

Diameter breast-high (inches).	Converting factor.	Diameter breast-high (inches).	Converting factor.
8	3.3	15	5.0
9	3.7	16	5.0
10	4.1	17	5.1
11	4.4	18	5.2
12	4.5	19	5.3
13	4.7	20	5.4
14	4.9		

Column 2 shows that for a tree 10 inches in diameter, breast-high, every cubic foot of volume in the tree is equal to 4.1 board feet, as determined by the Scribner rule, decimal C.

This table emphasizes the progressive increase in proportional board-foot contents of Norway pine, with increasing size, and the impossibility of converting cubic contents into board feet by a single multiple or ratio; these ratios apply only to the contents expressed by the Scribner rule.

The volume table is made by totaling for each tree the contents of logs of different diameters. No two log rules give the same contents in board feet for the same sized log, nor do they maintain the same proportional difference for logs of different sizes. Only by knowing the actual diameters of the logs in each tree can its volume by a new log rule be ascertained. Standard measurements of trees should for this reason be taken at definite intervals on every tree and averaged for trees of the same diameter and height. A table prepared in this manner, gives the average upper diameters of trees of all sizes and serves as a standard from which the volume may be found in any log rule or for any other unit of volume.

In Table 25, the results of 4,559 trees are averaged at points every 8 feet above an average stump height of 2 feet. An average length of 0.3 foot has been allowed on each 16-foot length for trimming.

TABLE 25.—*Diameter inside bark of Norway pine logs at intervals of 8.15 feet, on the basis of diameter, classed by trees of different heights.*

Diameter breast-high (inches).	Merchantable length (feet) including stump height.												
	10.15[1]	18.3	26.45	34.6	42.75	50.9	59.05	67.2	75.35	83.5	91.65	99.8	107.95
	(Diameter inside bark inches).												
	30-foot trees.												
2	1.3	1.1											
3	2.3	1.9											
4	3.1	2.5											
5	4.0	3.3											
6	4.9	3.9											
7	5.9	4.5											
8	6.6	5.1											
9	7.5	5.6											
10	8.3	6.1											
	40-foot trees.												
2	1.6	1.4	1.0										
3	2.5	2.2	1.6										
4	3.3	2.9	2.2										
5	4.2	3.7	2.8										
6	4.9	4.3	3.3										
7	5.8	5.1	3.9										
8	6.7	5.8	4.4										
9	7.5	6.5	4.8										
10	8.4	7.1	5.3										
11	9.3	7.7	5.7										
12	10.1	8.3	6.1										
13	11.0	9.1	6.5										
14	11.9	9.7	6.9										

[1] The stump height is 2 feet.

Table 25.—*Diameter inside bark of Norway pine logs at intervals of 8.15 feet, on the basis of diameter, classed by trees of different heights*—Continued.

Diameter breast-high (inches).	Merchantable length (feet) including stump height.												
	10.15[1]	18.3	26.45	34.6	42.75	50.9	59.05	67.2	75.35	83.5	91.65	99.8	107.95
	Diameter inside bark (inches).												
	50-foot trees.												
4	3.4	3.1	2.7	2.1	......	......	......	......	......	......	......	......	......
5	4.3	4.0	3.4	2.6	......	......	......	......	......	......	......	......	......
6	5.0	4.7	4.1	3.1	......	......	......	......	......	......	......	......	......
7	5.9	5.4	4.7	3.6	......	......	......	......	......	......	......	......	......
8	6.8	6.2	5.4	4.1	......	......	......	......	......	......	......	......	......
9	7.6	6.9	6.0	4.7	......	......	......	......	......	......	......	......	......
10	8.5	7.7	6.6	5.1	......	......	......	......	......	......	......	......	......
11	9.4	8.4	7.3	5.6	......	......	......	......	......	......	......	......	......
12	10.3	9.1	7.9	6.1	......	......	......	......	......	......	......	......	......
13	11.2	9.9	8.5	6.6	......	......	......	......	......	......	......	......	......
14	12.1	10.6	9.1	7.1	......	......	......	......	......	......	......	......	......
15	12.9	11.5	9.8	7.5	......	......	......	......	......	......	......	......	......
16	13.8	12.1	10.4	8.0	......	......	......	......	......	......	......	......	......
17	14.7	12.9	11.1	8.5	......	......	......	......	......	......	......	......	......
18	15.6	13.7	11.7	8.9	......	......	......	......	......	......	......	......	......
	60-foot trees.												
4	3.5	3.3	3.0	2.5	2.1	1.3	......	......	......	......	......	......	......
5	4.3	4.0	3.7	3.1	2.5	1.6	......	......	......	......	......	......	......
6	5.2	4.8	4.4	3.8	3.0	1.9	......	......	......	......	......	......	......
7	6.0	5.5	5.1	4.4	3.5	2.3	......	......	......	......	......	......	......
8	6.9	6.4	5.9	5.0	4.1	2.6	......	......	......	......	......	......	......
9	7.7	7.1	6.5	5.7	4.5	2.9	......	......	......	......	......	......	......
10	8.6	7.9	7.3	6.3	5.1	3.2	......	......	......	......	......	......	......
11	9.5	8.7	8.0	7.0	5.5	3.5	......	......	......	......	......	......	......
12	10.4	9.5	8.7	7.6	6.0	3.8	......	......	......	......	......	......	......
13	11.3	10.3	9.4	8.2	6.5	4.1	......	......	......	......	......	......	......
14	12.2	11.1	10.2	8.8	7.0	4.4	......	......	......	......	......	......	......
15	13.1	11.9	10.8	9.4	7.5	4.7	......	......	......	......	......	......	......
16	14.0	12.7	11.6	10.1	8.0	5.0	......	......	......	......	......	......	......
17	14.9	13.5	12.3	10.7	8.5	5.3	......	......	......	......	......	......	......
18	15.8	14.3	12.9	11.3	9.0	5.6	......	......	......	......	......	......	......
19	16.7	15.1	13.7	12.0	9.5	5.9	......	......	......	......	......	......	......
20	17.5	15.8	14.4	12.5	10.0	6.1	......	......	......	......	......	......	......
21	18.4	16.7	15.1	13.2	10.4	6.5	......	......	......	......	......	......	......
22	19.3	17.5	15.8	13.8	11.0	6.7	......	......	......	......	......	......	......
	70-foot trees.												
6	5.2	4.9	4.6	4.3	4.0	3.6	2.6	......	......	......	......	......	......
7	6.1	5.7	5.3	5.0	4.5	4.0	2.9	......	......	......	......	......	......
8	7.0	6.5	6.1	5.7	5.1	4.5	3.1	......	......	......	......	......	......
9	7.8	7.2	6.8	6.4	5.7	4.9	3.4	......	......	......	......	......	......
10	8.6	8.1	7.6	7.0	6.3	5.3	3.7	......	......	......	......	......	......
11	9.5	8.9	8.4	7.7	6.9	5.7	3.9	......	......	......	......	......	......
12	10.5	9.8	9.1	8.5	7.5	6.2	4.2	......	......	......	......	......	......
13	11.4	10.5	9.9	9.1	8.1	6.6	4.4	......	......	......	......	......	......
14	12.3	11.4	10.6	9.8	8.7	7.1	4.7	......	......	......	......	......	......
15	13.2	12.3	11.4	10.5	9.3	7.5	5.0	......	......	......	......	......	......
16	14.1	13.1	12.2	11.3	9.9	8.0	5.2	......	......	......	......	......	......
17	15.0	14.0	13.0	11.9	10.4	8.4	5.4	......	......	......	......	......	......
18	15.9	14.9	13.8	12.6	11.0	8.9	5.7	......	......	......	......	......	......
19	16.8	15.7	14.5	13.2	11.5	9.3	5.9	......	......	......	......	......	......
20	17.7	16.6	15.3	13.9	12.2	9.7	6.1	......	......	......	......	......	......
21	18.7	17.5	16.1	14.5	12.7	10.2	6.4	......	......	......	......	......	......
22	19.6	18.3	16.9	15.3	13.3	10.6	6.6	......	......	......	......	......	......
23	20.5	19.2	17.7	15.9	13.7	11.1	6.9	......	......	......	......	......	......
24	21.5	20.0	18.5	16.6	14.3	11.5	7.1	......	......	......	......	......	......
25	22.4	20.9	19.2	17.2	14.9	11.9	7.3	......	......	......	......	......	......
26	23.3	21.8	20.1	18.0	15.5	12.3	7.6	......	......	......	......	......	......

[1] The stump height is 2 feet.

TABLE 25.—*Diameter inside bark of Norway pine logs at intervals of 8.15 feet, on the basis of diameter, classed by trees of different heights*—Continued.

Diameter breast-high (inches).	Merchantable length (feet) including stump height.												
	10.15 [1]	18.3	26.45	34.6	42.75	50.9	59.05	67.2	75.35	83.5	91.65	99.8	107.95
	Diameter inside bark (inches).												
	80-foot trees.												
6	5.3	5.0	4.9	4.7	4.5	4.2	3.7	2.6	......	......	......	......	......
7	6.2	5.9	5.6	5.5	5.1	4.7	4.1	2.9	......	......	......	......	......
8	7.1	6.7	6.4	6.1	5.7	5.3	4.6	3.3	......	......	......	......	......
9	8.0	7.5	7.2	6.9	6.3	5.8	5.0	3.6	......	......	......	......	......
10	8.9	8.3	7.9	7.5	7.1	6.5	5.5	4.0	......	......	......	......	......
11	9.7	9.2	8.7	8.2	7.7	7.0	5.9	4.3	......	......	......	......	......
12	10.7	10.0	9.5	8.9	8.3	7.6	6.4	4.6	......	......	......	......	......
13	11.5	10.9	10.3	9.7	8.9	8.1	6.7	4.9	......	......	......	......	......
14	12.4	11.6	11.0	10.3	9.6	8.7	7.2	5.2	......	......	......	......	......
15	13.3	12.5	11.9	11.1	10.3	9.3	7.7	5.6	......	......	......	......	......
16	14.2	13.4	12.6	11.8	10.9	9.9	8.1	5.9	......	......	......	......	......
17	15.1	14.2	13.4	12.6	11.7	10.4	8.6	6.2	......	......	......	......	......
18	16.0	15.1	14.2	13.3	12.3	11.0	9.1	6.5	......	......	......	......	......
19	16.9	15.9	15.1	14.1	13.0	11.6	9.5	6.7	......	......	......	......	......
20	17.8	16.7	15.9	14.9	13.7	12.2	9.9	7.0	......	......	......	......	......
21	18.7	17.5	16.6	15.6	14.4	12.7	10.3	7.3	......	......	......	......	......
22	19.6	18.4	17.4	16.3	15.0	13.3	10.8	7.6	......	......	......	......	......
23	20.5	19.2	18.2	17.1	15.7	13.9	11.2	7.9	......	......	......	......	......
24	21.3	20.0	19.1	17.9	16.4	14.5	11.7	8.1	......	......	......	......	......
25	22.2	20.9	19.8	18.7	17.2	15.1	12.1	8.4	......	......	......	......	......
26	23.0	21.7	20.6	19.3	17.7	15.7	12.5	8.7	......	......	......	......	......
27	23.9	22.5	21.5	20.2	18.5	16.3	13.0	9.0	......	......	......	......	......
28	24.7	23.5	22.3	20.9	19.2	16.9	13.5	9.2	......	......	......	......	......
29	25.6	24.3	23.1	21.8	19.9	17.5	13.9	9.5	......	......	......	......	......
30	26.5	25.1	24.0	22.5	20.6	18.1	14.4	9.8	......	......	......	......	......
	90-foot trees.												
6	5.4	5.1	5.0	4.8	4.6	4.3	4.0	3.5	2.8	1.5	......	......	......
7	6.2	6.0	5.8	5.5	5.2	4.9	4.6	4.0	3.1	1.6	......	......	......
8	7.2	6.9	6.7	6.3	5.9	5.5	5.2	4.5	3.5	1.8	......	......	......
9	8.0	7.7	7.4	7.1	6.6	6.3	5.8	5.0	3.8	1.9	......	......	......
10	8.9	8.5	8.3	7.8	7.3	6.9	6.3	5.4	4.1	2.1	......	......	......
11	9.8	9.3	8.9	8.5	8.0	7.5	6.9	5.9	4.5	2.3	......	......	......
12	10.7	10.2	9.8	9.3	8.7	8.2	7.5	6.4	4.8	2.4	......	......	......
13	11.6	11.0	10.6	10.1	9.5	8.8	8.1	6.9	5.1	2.6	......	......	......
14	12.5	11.9	11.3	10.8	10.2	9.5	8.7	7.3	5.5	2.7	......	......	......
15	13.4	12.7	12.1	11.5	10.9	10.2	9.2	7.8	5.8	2.9	......	......	......
16	14.3	13.5	12.9	12.3	11.6	10.8	9.7	8.2	6.1	3.0	......	......	......
17	15.1	14.3	13.7	13.0	12.4	11.5	10.3	8.7	6.4	3.2	......	......	......
18	16.1	15.2	14.5	13.8	13.1	12.2	10.9	9.1	6.7	3.3	......	......	......
19	16.9	16.0	15.2	14.5	13.8	12.9	11.5	9.6	7.0	3.5	......	......	......
20	17.9	16.9	16.1	15.3	14.6	13.5	12.1	10.1	3.6	3.6	......	......	......
21	18.7	17.7	16.8	16.1	15.3	14.2	12.6	10.5	7.7	3.8	......	......	......
22	19.7	18.5	17.6	16.9	16.1	14.9	13.2	10.9	8.0	3.9	......	......	......
23	20.5	19.4	18.4	17.6	16.8	15.5	13.7	11.4	8.3	4.1	......	......	......
24	21.5	20.2	19.2	18.4	17.6	16.3	14.3	11.8	8.6	4.3	......	......	......
25	22.3	21.0	20.0	19.2	18.3	16.9	14.9	12.2	8.9	4.4	......	......	......
26	23.2	21.8	20.8	19.9	19.1	17.7	15.4	12.6	9.2	4.6	......	......	......
27	24.0	22.7	21.6	20.7	19.8	18.3	15.9	13.0	9.5	4.7	......	......	......
28	24.8	23.4	22.4	21.5	20.6	19.0	16.5	13.5	9.9	4.9	......	......	......
29	25.7	24.2	23.2	22.3	21.3	19.6	17.1	14.0	10.2	5.1	......	......	......
30	26.5	25.0	24.0	23.1	22.0	20.3	17.5	14.4	10.5	5.3	......	......	......
31	27.4	25.8	24.8	23.9	22.7	20.9	18.2	14.8	10.8	5.4	......	......	......
32	28.3	26.5	25.5	24.7	23.5	21.5	18.6	15.2	11.1	5.6	......	......	......
33	29.1	27.3	26.4	25.5	24.2	22.2	19.3	15.7	11.5	5.8	......	......	......
34	30.0	28.1	27.2	26.3	25.0	22.8	19.8	16.2	11.8	6.0	......	......	......
	100-foot trees.												
8	7.3	7.1	6.8	6.5	6.0	5.6	5.3	5.0	4.4	3.3	1.9	......	......
9	8.2	8.0	7.6	7.3	6.8	6.3	5.9	5.5	4.8	3.7	2.0	......	......
10	9.1	8.8	8.4	8.0	7.5	7.0	6.5	6.1	5.3	3.9	2.2	......	......
11	10.0	9.7	9.2	8.8	8.3	7.7	7.2	6.6	5.7	4.2	2.4	......	......
12	10.9	10.5	10.0	9.5	9.0	8.5	7.8	7.1	6.2	4.6	2.5	......	......
13	11.7	11.3	10.8	10.3	9.7	9.1	8.5	7.7	6.6	4.9	2.7	......	......

[1] The stump height is 2 feet.

TABLE 25.—*Diameter inside bark of Norway pine logs at intervals of 8.15 feet, on the basis of diameter, classed by trees of different heights*—Continued.

Diameter breast-high (inches).	Merchantable length (feet) including stump height												
	10.15[1]	18.3	26.45	34.6	42.75	50.9	59.05	67.2	75.35	83.5	91.65	99.8	107.95
	Diameter inside bark (inches).												
	100-foot trees—continued.												
14	12.6	12.0	11.5	11.0	10.5	9.9	9.1	8.3	7.0	5.1	2.9	......	......
15	13.5	12.9	12.3	11.7	11.2	10.6	9.7	8.8	7.5	5.4	3.0	......	......
16	14.4	13.7	13.1	12.5	12.0	11.3	10.4	9.3	7.8	5.7	3.2	......	......
17	15.2	14.5	13.8	13.2	12.7	12.0	11.1	9.8	8.3	6.0	3.3	......	......
18	16.1	15.4	14.6	14.0	13.5	12.7	11.7	10.4	8.7	6.3	3.4	......	......
19	17.0	16.1	15.4	14.8	14.2	13.4	12.3	10.9	9.1	6.6	3.6	......	......
20	17.9	17.0	16.1	15.5	15.0	14.2	13.0	11.5	9.5	6.9	3.8	......	......
21	18.8	17.8	16.9	16.3	15.7	14.9	13.7	12.0	10.0	7.2	3.9	......	......
22	19.7	18.6	17.7	17.1	16.5	15.6	14.3	12.6	10.4	7.5	4.1	......	......
23	20.6	19.4	18.5	17.9	17.3	16.3	14.9	13.2	10.9	7.9	4.2	......	......
24	21.5	20.2	19.3	18.7	18.0	17.1	15.6	13.7	11.4	8.2	4.4	......	......
25	22.3	21.1	20.1	19.5	18.9	17.8	16.2	14.3	11.9	8.5	4.5	......	......
26	23.3	21.9	20.9	20.3	19.6	18.5	16.9	14.9	12.3	8.8	4.8	......	......
27	24.1	22.7	21.7	21.1	20.4	19.3	17.6	15.5	12.8	9.2	4.9	......	......
28	25.0	23.5	22.5	21.9	21.1	20.0	18.2	16.0	13.3	9.5	5.1	......	......
29	25.9	24.3	23.3	22.6	21.9	20.7	18.8	16.6	13.7	9.9	5.3	......	......
30	26.7	25.1	24.1	23.5	22.6	21.3	19.5	17.2	14.1	10.2	5.5	......	......
31	27.6	26.0	24.9	24.1	23.3	22.0	20.1	17.7	14.7	10.6	5.7	......	......
32	28.5	26.7	25.7	25.0	24.1	22.8	20.6	18.2	15.1	10.8	5.9	......	......
33	29.3	27.5	26.6	25.8	24.8	23.4	21.3	18.7	15.5	11.2	6.0	......	......
34	30.2	28.3	27.4	26.5	25.5	24.0	21.9	19.3	15.9	11.5	6.3	......	......
	110-foot trees.												
12	11.0	10.5	10.0	9.5	9.1	8.5	7.8	7.1	6.3	5.1	3.7	2.1	......
13	11.8	11.3	10.7	10.2	9.8	9.2	8.5	7.7	6.8	5.5	4.0	2.3	......
14	12.7	12.1	11.5	11.1	10.6	10.0	9.3	8.3	7.3	6.0	4.4	2.5	......
15	13.5	12.9	12.3	11.7	11.3	10.7	9.9	9.0	7.8	6.4	4.7	2.7	......
16	14.5	13.7	13.1	12.5	12.1	11.5	10.7	9.6	8.5	6.9	5.1	2.9	......
17	15.3	14.4	13.8	13.3	12.8	12.1	11.3	10.2	8.9	7.3	5.3	3.1	......
18	16.2	15.3	14.6	14.1	13.6	13.0	12.1	10.9	9.6	7.8	5.7	3.3	......
19	17.1	16.1	15.3	14.7	14.3	13.7	12.7	11.5	10.1	8.2	6.1	3.5	......
20	17.9	16.9	16.1	15.6	15.1	14.5	13.5	12.3	10.7	8.7	6.4	3.7	......
21	18.8	17.7	17.0	16.4	15.9	15.1	14.1	12.8	11.2	9.1	6.7	3.9	......
22	19.7	18.6	17.7	17.2	16.7	15.9	14.9	13.6	11.8	9.6	7.1	4.1	......
23	20.6	19.4	18.6	18.0	17.5	16.7	15.6	14.2	12.4	10.1	7.4	4.3	......
24	21.5	20.3	19.4	18.8	18.3	17.4	16.3	14.9	13.0	10.6	7.8	4.4	......
25	22.4	21.1	20.2	19.5	19.0	18.1	16.9	15.5	13.5	11.0	8.1	4.6	......
26	23.3	21.9	21.0	20.4	19.8	18.9	17.7	16.2	14.1	11.6	8.5	4.9	......
27	24.2	22.7	21.9	21.2	20.6	19.7	18.4	16.8	14.7	12.0	8.8	5.1	......
28	25.1	23.5	22.6	22.0	21.4	20.5	19.1	17.5	15.3	12.5	9.2	5.3	......
29	26.0	24.5	23.5	22.7	22.1	21.2	19.9	18.1	15.9	13.0	9.6	5.5	......
30	26.9	25.3	24.2	23.6	23.0	22.0	20.6	18.8	16.4	13.5	10.0	5.7	......
31	27.8	26.1	25.1	24.4	23.7	22.8	21.3	19.5	17.1	14.0	10.4	6.0	......
32	28.7	26.9	25.8	25.1	24.5	23.6	22.1	20.1	17.6	14.5	10.7	6.1	......
33	29.7	27.7	26.7	26.0	25.3	24.3	22.7	20.8	18.2	15.0	11.1	6.5	......
34	30.6	28.5	27.5	26.8	26.2	25.1	23.5	21.4	18.8	15.5	11.5	6.6	......
	120-foot trees.												
16	14.3	13.6	12.9	12.3	11.8	11.2	10.6	9.7	8.7	7.5	6.0	4.3	2.6
17	15.3	14.4	13.8	13.1	12.6	12.1	11.4	10.5	9.4	8.2	6.5	4.7	2.9
18	16.2	15.3	14.6	14.0	13.4	12.8	12.1	11.1	10.0	8.6	7.0	5.2	3.2
19	17.1	16.1	15.4	14.8	14.3	13.6	12.9	11.9	10.6	9.2	7.6	5.6	3.5
20	18.0	16.9	16.2	15.6	15.0	14.4	13.7	12.6	11.3	9.8	8.1	6.0	3.8
21	18.9	17.8	17.0	16.4	15.9	15.2	14.4	13.3	12.0	10.4	8.6	6.4	4.1
22	19.8	18.7	17.8	17.3	16.7	16.0	15.2	14.0	12.6	11.0	9.1	6.8	4.4
23	20.7	19.5	18.6	18.1	17.5	16.8	15.9	14.8	13.3	11.6	9.6	7.2	4.7
24	21.6	20.4	19.4	18.9	18.4	17.6	16.7	15.4	13.9	12.1	10.1	7.7	4.9
25	22.5	21.2	20.3	19.7	19.2	18.5	17.4	16.1	14.6	12.8	10.7	8.1	5.3
26	23.5	22.0	21.1	20.5	20.0	19.2	18.2	16.9	15.2	13.4	11.1	8.5	5.5
27	24.3	22.9	21.9	21.3	20.8	20.1	19.0	17.7	15.9	13.9	11.7	8.9	5.8
28	25.3	23.7	22.8	22.1	21.6	20.9	19.8	18.3	16.5	14.5	12.2	9.2	5.9
29	26.2	24.6	23.6	23.0	22.5	21.7	20.5	19.1	17.3	15.1	12.7	9.7	6.2
30	27.1	25.5	24.4	23.8	23.3	22.5	21.4	19.8	17.9	15.7	13.2	10.1	6.5
31	28.0	26.3	25.3	24.6	24.1	23.4	22.1	20.6	18.7	16.3	13.7	10.5	6.9
32	28.9	27.2	26.1	25.4	24.9	24.1	22.9	21.4	19.3	16.9	14.2	11.0	7.2
33	29.8	28.0	26.9	26.2	25.7	24.9	23.7	22.2	20.0	17.5	14.8	11.4	7.4
34	30.7	28.9	27.8	27.1	26.6	25.8	24.6	22.9	20.7	18.2	15.3	11.8	7.7

[1] The stump height is 2 feet.

To construct a volume table from the upper diameters or tapers given in Table 25, the average top diameter to which trees are utilized must be known. In species possessing a regular form this may be a fixed limit, as 6 inches, regardless of the size of the tree. But where utilization is not close, and tops are heavy, with large limbs, the diameter limit in the top will increase with the diameter of the tree. With this top diameter determined, the taper table will indicate the merchantable length for each diameter and height class to the nearest 8-foot length. For board feet, adapting a 16-foot log, the upper diameters of each log in the tree enable one to secure the scaled contents by the desired log rule.

The number of standard railroad ties or products of other known dimensions may also be found for trees of any size from this table.

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Contribution from the Bureau of Soils
MILTON WHITNEY, Chief

Washington, D. C. ▼ April 5, 1915

SOILS OF MASSACHUSETTS AND CONNECTICUT WITH ESPECIAL REFERENCE TO APPLES AND PEACHES

By

HENRY J. WILDER, Scientist in Soil Survey

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SOILS OF MASSACHUSETTS AND CONNECTICUT, WITH ESPECIAL REFERENCE TO APPLES AND PEACHES.

By HENRY J. WILDER, *Scientist in Soil Survey.*

SURFACE FEATURES.

Southern New England consists of a hilly plateau highest at the northwest and lowest along the seashore, the elevation showing a general range from less than 50 feet at the shore to 1,800 feet in the northwest, with an extreme altitude at Mount Greylock of 3,505 feet.

The surface features of this area are locally complex, but it is nevertheless naturally divided into three upland blocks and two lowland belts. These are, beginning at the west, the Taconic Mountain section, with general elevation of 1,200 to 2,800 feet; the Berkshire Valley; the Western Plateau, with general elevation ranging from sea level on the south to 1,800 feet; the Connecticut Valley; and the Eastern Plateau, extending from the Connecticut Basin to the coast with general elevation ranging from sea level on the east and south to 1,200 feet.

For convenience in discussing the relation of the soil factor to fruit growing, and because of the importance of the elevation factor in such study, the Eastern Plateau is further divided on the basis of elevation into the Coastal district; the Framingham-Boston lowlands; the Eastern and Southeastern Plateau, with general elevation of 200 to 700 feet; and the Eastern Highlands, with general elevation of 700 to 1,200 feet, the lower part of this section being superseded on the south by an extension of the Southeastern Plateau. Figure 1 shows the extent and relations of these several divisions.

THE COASTAL DISTRICT.

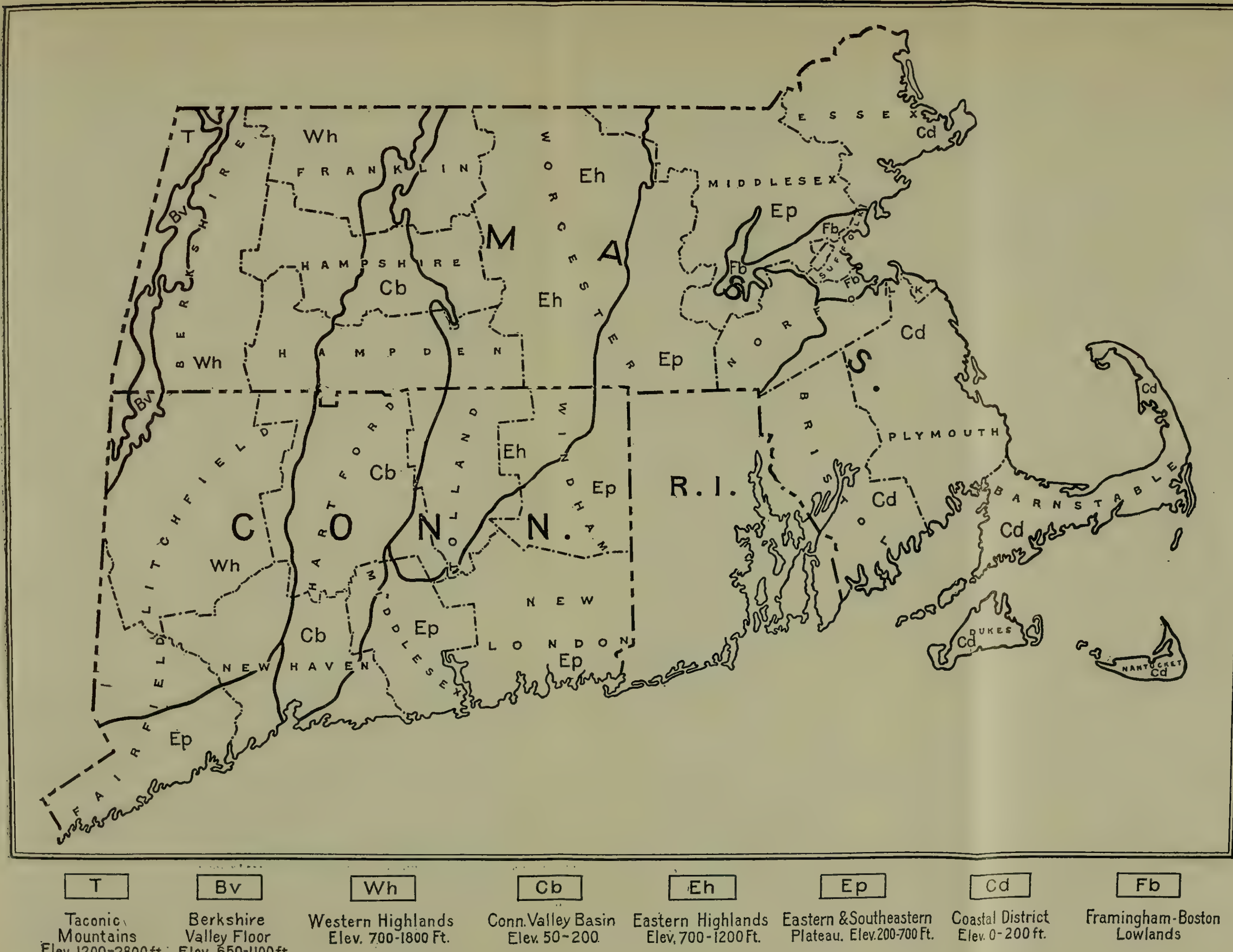
The Coastal Plain of the eastern United States does not extend northward, in typical development at least, to southern New England. The country from Plymouth-New Bedford eastward and northward, with its absence of rock outcrops and the predominance of sandy soils, is a near approach to it. East of a line drawn from the northeast corner of Rhode Island to Blue Hill the country is in elevation above the sea level and in relation to higher land westward similar to the Coastal Plain. The main body of this southeastern section is marked here and there by low hills and isolated ridges, giving it a gently rolling appearance, though in places it is almost plainlike. In general the topography east of this line consists of broad, low, rounded hills and ridges, with intervening smooth or faintly dissected plains. West of this line the hills and ridges are sharper, higher, and more thickly set on the landscape, while the smooth plains become narrower. East of it the plains are the predominant topographic feature. West of it the hills are predominant. The change, however, is gradual rather than abrupt, and the dividing line described above is only approximate.

The Framingham-Boston district includes an area topographically intermediate between the two areas described above, in which there are numerous low but steep hills and ridges standing in broad, smooth plains, a considerable part of which is swampy. This is a local district, which extends for a short distance into the more extensive Eastern Plateau, and west of Waltham it consists of a relatively narrow belt lying to the west of the Wellesley Hills.

THE EASTERN PLATEAU.

The boundaries of the Eastern Plateau are shown on the sketch map, figure 1, and need no further description here. The eastern boundary is so placed because of the much higher general altitude of the Highland district which lies to the west in Massachusetts and to the west and north in Connecticut. This district thus includes all the southeastern part of the latter State, in which it constitutes the largest topographic division. The elevation boundaries may be easily traced by the contour lines of the United States Geological Survey topographic sheets. The width of this section in Massachusetts is about 35 miles at the center of the State, but on a line with Cape Ann it is much more. The elevation of the principal hills along the east boundary of this region may be approximated as 200 feet, and along the western boundary as something above 600 feet, with isolated points about 700 feet. In Connecticut this district includes approximately the southeastern third of the State, including all of New London County and the greater part of Windham and Middlesex Counties.

Were all the valleys and depressions filled to the average height of the adjacent hills, there would result a high plain, sloping from the boundary of the eastern highland toward the sea. Some of the highest elevations, however, would rise above such plain, thus pro-



FIGURES GIVEN SHOW THE GENERAL ELEVATION RANGE

Fig. 1.—Sketch-map showing physiographic divisions of Southern New England.

55570°—Bull. 140—15. (To face p. 2.)

ducing a gently rolling surface. Dissection of this plateau through a long period of time has been so pronounced that the existing surface is extremely irregular. It is a succession of much worn-down knobs and hills, with narrow intervening valleys. The hills are multiformed. Some are steep, and others not only steep but small, thus rendering cultivation expensive. Others, however, are dome-shaped, or at least sufficiently regular and smooth to afford many good farming areas and sites for orchards.[1] The higher parts consist of isolated hills or chains of hills, with much less definite direction than those of the Highland section adjoining on the west, where the trend ranges from north and south to northeast and southwest, as in all of both States farther west. The dome-shaped hills that frequently characterize this section are much more rare in the Western Plateau. The northern part of the Eastern Plateau is drained by the Merrimac River, of which the two principal branches are the Concord and the Nashua Rivers. Much of the Concord River basin is drained by its two important branches, the Sudbury and the Assabet Rivers. The southern part of the region is drained by the Charles, the Blackstone, and the French Rivers.

THE EASTERN HIGHLAND.

The Eastern Highland extends from the Eastern Plateau to the Connecticut Valley Basin. Its general slope is southerly, and the general range in elevation, barring exceptionally low and exceptionally high points, is from 700 to 1,200 feet. The high hills are somewhat broader in the northern part than in the southern, a fact which undoubtedly led in colonial days to the establishment of villages on several of these elevations ranging in altitude from 1,000 to 1,200 feet. Some of the villages in such locations are Shutesbury, Wendell, New Salem, Prescott, Pelham, Petersham, Phillipston, Templeton, Rutland, Oakham, New Braintree, Wilmington, Mansfield, Gilead, and Winchester.

The drainage of the Eastern Highland is mostly to the west and to the southwest. In the northern part Millers River rises in the vicinity of Gardner, flows due west, and enters the Connecticut near Millers Falls. In the central part the Swift, the Ware, and the Quabaug Rivers have their sources. These streams flow together at the town of Three Rivers, forming the Chicopee River, which enters the Connecticut at Chicopee. The extreme southeastern part of the

[1] The apple census of Massachusetts prepared by the State board of agriculture for the year 1905 shows the highest producing areas to be in those sections where this dome-shaped topography is most characteristic. This is an adaptation to conditions of topography and soil that had gradually come to be apparent, as the deepest and most productive soils of each section in southern New England are usually located in this favorable topographic position. Erosion also is not serious and tillage is relatively economical.

highland is drained by the headwaters of the Quinebaug River, which flows south into the State of Connecticut.

The general upland surface of this division is strikingly interrupted in its northern part by three prominent isolated mountains—Mount Watatic, Mount Grace, and Mount Wachusett—1,847, 1,628, and 2,108 feet in elevation, respectively.

THE CONNECTICUT VALLEY BASIN.

The Connecticut Valley region consists of a broad basin, which succeeds the Eastern Highland on the west and crosses both States from north to south. Approximately along its axial line lies the Connecticut Valley, a shallow, flat-bottomed trough, from less than 1 to more than 3 miles in width, through which meanders the river of the same name. The distance from the river due east to Boston is approximately 100 miles, and from the river due west to the New York line about 50 miles. The topography of the basin is generally smooth, becoming rolling locally, and is traversed by narrow but rugged ridges. It is a region of good soils and well-developed agriculture. The eastern boundary slope of the basin is more nearly a wall than a slope. The western slope is much more gradual than the eastern. It soon merges into the Western Highland section, which forms a broad, dissected plateau with easterly slope. In Connecticut the valley is wider than in Massachusetts, being one-sixth the width of the State at North Haven and north of Hartford one-fourth the width of the State. Beginning south of Northampton, Mass., is a series of sharp ridges traversing the valley and dividing it into an eastern and a western area, the former being the broader in the northern and central parts of the State of Connecticut, while the western arm is the broader in the southern part of the State. The latter is known as the Farmington-Southington Valley. Aside from the ridges, both arms of the valley are smooth to undulating; rarely can any portions be called hilly.

THE WESTERN HIGHLANDS.

The crest of this plateau, which lies along its western boundary, is marked by the Hoosic Range, which reaches a height of more than 2,800 feet, and from which all drainage easterly goes to the Connecticut River. This lofty plateau corresponds to the highlands of New York and New Jersey, to the Reading Hills and South Mountain in Pennsylvania (the latter name continuing through Maryland), and to the Blue Ridge of Virginia and North Carolina. Extending into Vermont it becomes more mountainous than in Massachusetts, and soon merges into the Green Mountain Range, which reaches a maximum height of 4,364 feet. On the west the Hoosic Range descends almost abruptly to the deep, narrow Berkshire Valley, but on the east it drops a little less steeply to the plateau into which it merges.

On the south the Hoosic Mountain becomes less well defined south of the incision by the Westfield River, and in northern Connecticut breaks up into a local group of hills.

The surface of the western plateau shows a wide range of variation. There are, however; many localities with areas of smooth to rolling country. These occur on the watershed ridges and along the eastern foot slope of the Hoosic Range, where the streams are yet too small to have cut deep into the plateau. In many cases they form covelike basins in the eastern side of the ridge. Around the heads of many of the small ravines within the plateau, before their streams have cut their way deep into it, there are broad basins of thickly accumulated drift which are usually occupied as farms.

One of the largest areas of smooth, undissected land at high-plateau level lies in parts of the towns of Hawley, Plainfield, and Cummington. The farm lands of the western plateau occur on the high-plateau top, in valley-head basins below the top, in valley bottoms, and on lower-valley slopes. In the eastern plateau it is mainly on the dome-shaped hills and rounded smooth ridges.

THE BERKSHIRE VALLEY.

The Berkshire Valley forms a link in the chain of great limestone valleys stretching across the United States from Canada to Alabama. At North Adams this valley is about 10 miles, at Pittsfield 7 miles, and at Great Barrington 5 miles from the New York line. Its surface is rolling to hilly, much more so than the unglaciated limestone valleys forming other links in the chain, and in marked contrast to the comparatively level topography of the Connecticut Valley. The southern two-thirds of this valley is drained by the Housatonic River and the northern third by the Hoosac River.

The Berkshire Valley from the Vermont line to Williamstown is usually less than a mile in width. South of Williamstown it divides, the Green River arm being narrow soon crosses the State line into New York, reentering the main valley near Pittsfield. From Williamstown east to Braytonville the eastern arm is well developed, but at the latter point it narrows rapidly and is nearly closed by Bald Mountain and Ragged Mountain, north of North Adams. From the latter point south to Adams the valley is deep and narrow, rarely exceeding a half mile, and much of that is talus slope. Thence south to Cheshire Harbor the valley is almost V-shaped, but it then broadens toward Cheshire until the local reservoir occupies its bottom as far south as Pontoosuc Lake. Thence to Shaker Village and Pittsfield the valley is several miles wide, and at the former village a spur valley extends southwest to the State line. From

Pittsfield to Stockbridge the main valley is 1 to 2 miles wide, but it then is closed in by mountains. Near Great Barrington and the Egremonts it is again 5 miles wide. Narrowing at Sheffield to 3 miles it again broadens to 6 miles at the State line, narrowing again a few miles to the south. Across the western end of Connecticut it is broken into a number of small isolated areas.

THE TACONIC MOUNTAIN GROUP.

West of the Hoosac Valley lies a thick local mountainous group with general elevation above 2,000 feet, known as the Taconic Mountains. These mountains are parallel to the Housatonic Valley and form its western boundary. They lie partly in Massachusetts and partly in the State of New York. Their steep slopes afford little good farming land. Their highest point in Massachusetts is approximately 2,800 feet. Geologically these mountains and the lower region west to the Catskills correspond to the broad band of shales, which give rise to the Berks soils of Pennsylvania, where they adjoin on the north the Lehigh, Lebanon, and Cumberland Valleys.

The highest mountain in southern New England, Mount Greylock, with elevation of 3,505 feet, lies between the two branches of the Berkshire Valley, southeast of Williamstown, Mass.

The general surface of the Western and Eastern Highlands and of the Southeastern Plateau is very irregular, yet the upland skyline is approximately even. The surface of this sloping region passes beneath the sea along the existing shore line with no sudden descent. The coast line merely marks the points of zero elevation along this tilted surface. The rise is gradual to a maximum of 2,000 feet in the northwest corner of Massachusetts.

THE SOIL MATERIAL.

The soil material found in southern New England is called glacial material by geologists, meaning that it was placed where it now lies by deposition from a former ice sheet. It was removed a short distance, however, and to all intents and purposes it is the product of the weathering, breaking up, and more or less grinding up of the rocks which occur in the region and constitute its foundation.

These consist, with the exception of the rocks in the Connecticut Valley, of ancient crystalline rocks, such as gneisses, schists, slates, and various igneous rocks. They are, so far as the soil material is concerned and considered in a broad way, essentially uniform over the whole State. In the Connecticut Valley the rocks consist of soft sandstones and shales with a few bands of hard igneous rocks which form the ridges already referred to.

The Cape Cod region differs from the rest of the region in that the existing land and its elevation is not due to a solid rock foundation with a thin coating of soil material, but consists of an accumulation of unconsolidated rock material in which the rock foundation lies deep, seemingly below the level of the sea. It is in this respect similar to Long Island and to a certain extent to the Coastal Plain.

Southern New England has passed through a long history in reaching its present condition. It is unnecessary to recount even the broad phases of that history, since it can be obtained in any good geological description of the region. A late and the most important stage in that history, so far as the soils of the region are concerned, was the invasion of the region by the glaciers of the glacial period. This changed the details of surface relief, thoroughly mixed and rearranged and redistributed the preexisting coating of soil and soil material, making the formation of a new soil necessary. The existing soils, therefore, are the product of soil-making agencies that have been in operation since the glacial period and are therefore young.

The ice reshaped the details of the topography by rounding off sharp corners and filling basins with deposits. Although part of the country is mountainous it has been rounded so that most of it is easily accessible.

The ice modified the layer of soil material in several ways:

(1) It removed a coating that was due to weathering and therefore approximately uniform in thickness, and left one that is practically absent in some places and of great thickness in others.

(2) It left a layer of soil material usually mixed with stone fragments.

(3) Owing to the great amount of water that was released from the ice during the melting period many belts and areas were built up into flat plains by the deposition of gravel and sand. These lie in the low belts and their proportional area increases progressively eastward from the Connecticut Valley.

(4) In some areas a very irregular and a very stony deposit was made in which the irregularities are small, giving a rough, bumpy, topography. These areas are usually very stony and almost worthless for agriculture.

We have, therefore—

(1) The smooth, moderately stony surfaces that may be level, moderately steep, or rolling. The soils consist of loams, clay loams, and sands.

(2) Level, sandy, and gravelly areas.

(3) Bumpy stony gravelly or sandy areas.

(4) Very steep areas and rocky areas.

The agriculture of New England is mainly on No. 1.

CLIMATE.

The climate of southern New England is rigorous, but the seasons are of sufficient length for the securing of good crops, and seem especially favorable for a long list of varieties of apples. It is essential, of course, with all field crops, to select varieties that will mature in the prevailing length of season, but the yields obtained clearly demonstrate that this is no handicap. In fact, the range of crop varieties available is distinctly favorable. This is undoubtedly due in part to the long-continued line of horticulturists and seedsmen in the region who have been interested in varietal development, but the fact that the climate is suitable for a wide range of varieties, especially of horticultural varieties, is unquestionable. This is evidenced by the fact that 134 varieties have been listed by the United States Department of Agriculture [1] as having originated in Massachusetts. Prof. Beach, in "The Apples of New York," mentions 27 of these varieties, of which the following 5 may be termed commercial: Baldwin, Hubbardston, Roxbury, Sutton, and Williams. Connecticut is credited with 88 varieties,[1] of which one, the Twenty-ounce, is in the commercial list. It may be added for the sake of comparison that New York is credited with a far greater number, 176 varieties,[1] but of these only 6 are commercial, viz: Fall Pippin, Jonathan, Yellow Newtown, Northern Spy, Tompkins King, and Wagener. Rhode Island is credited with only 9 varieties,[1] but two of these are commercial—the Rhode Island Greening and the Tolman Sweet. A number of secondary varieties have also originated in most of these States, some of almost commercial importance and other highly desirable for family use.

To the peach growers of Connecticut the climatic conditions within that State are of much importance. No section is free from frost injury or occasional winter injuring due to low temperatures, but accumulated experience has led to the establishment of most of the commercial peach orchards along the lateral slopes of the Central Lowland belt or on local elevations within it. In the southern part of the State also, at elevations below 600 feet, occasional commercial orchards give excellent results, but the largest of these have been established by men of experience on good local elevations at least a few miles back from the shore. The loss of fruit from strong onshore winds seems to account for the last precaution. In the northeastern part of the State, at medium to higher elevations, peaches are grown with moderate financial success, but the average climatic risk is a little greater; only the occasional man engages in it, and even then usually as a money crop rather than as a main business. There is a general feeling, too, that the soils are somewhat less favorable for peaches than in the Central

[1] Bul. 56, Bureau of Plant Industry, U. S. Dept. of Agr.

Lowland district. In Massachusetts, however, in southeastern Worcester, southwestern Middlesex, and western Norfolk Counties, good results have been secured. In the northern two-thirds of the Western Highlands the climate is generally considered too severe for commercial peach orcharding, though scattering orchards are more or less successful. Isotherms of the weather maps indicate within rough limits the peach-growing sections and the nonpeach-growing sections as already outlined. But if weather conditions had been the only determining factor in the location of the peach industry, the orchards of the State would not have been distributed as they now are. In general the slopes along the west side of the Central basin have much fewer peach orchards than the slopes along the eastern side, and although there are very few orchards in the latter position between Hartford, Conn., and the Massachusetts line, an important development occurs just north of the State boundary in the Wilbraham district.

The development of peach orcharding has already proved that climatic conditions favoring the business obtain in considerable areas of the State, and that only a small percentage of such areas have been developed. It is true, of course, that only a small part of the soils of such climatic areas are the most desirable, but such tracts readily may be selected, and they include many undeveloped local areas of good peach soils.

Barring low-lying areas the climatic conditions of the whole State are well suited to apple growing, though the character of the fruit varies with the kind of soil and not improbably to some extent with the range in climate—i. e., a Baldwin grown on a certain soil 1,000 feet above sea level in the northwest part of the State matures a little later and it seems reasonable to suppose that it may possess a little better keeping qualities than one grown 40 miles farther south on the same character of soil at an elevation of 500 feet; and while this point is generally conceded by growers, it would be of greater value if supported by experimental data to measure as nearly as may be the amount of this difference.

SOILS OF SOUTHERN NEW ENGLAND.

The soil materials of southern New England, the rocks from which they have been derived, and the glacial processes by which they were accumulated in their present positions have been described. These are factors of great importance in determining the character of the soil, but they are not the exclusive ones. The most important additional factors are drainage, chemical change, and the accumulation of vegetable matter. These latter are equally as important in determining the productive power of the soil as are the former.

Since this report is not primarily a soil-survey report, the details of location and character of the different soils can not be given; but the main soil groups of southern New England are relatively simple, though the details are complex. Soil groups are given a name, the members in the group constituting what is technically called a soil series. A soil series includes all soils with the same origin, color, character of subsoil, and all other characteristics except texture, or the coarseness or fineness of the soil particles.

The most widely distributed soil series in southern New England has been named the Gloucester series. It is typically brown in color, grading toward a yellowish color on the one hand and a light-brown color on the other. The subsoil is typically yellowish brown in color and usually as heavy or heavier than the soil. In the heavier members of the series in the lower subsoil, from about 24 to 36 inches and deeper, the color sometimes changes to a drab or bluish color. The soils of the series are well drained and aerated, uniformly oxidized, and when they occur on smooth areas and have a fair to good supply of vegetable matter are productive. They are derived from the crystalline rocks of the region, and the material was accumulated by deposition from the ice of the glacial period. They occur on the rolling and hilly uplands of the region. They are usually stony, but do not have gravel or sand subsoils except possibly in rare cases. Their water-holding capacity is normally good. Occasionally the clay subsoil is rather compact, resembling a hardpan, but true chemical hardpans are practically unknown. The most prevalent members of the Gloucester series are the loam and the sandy loams, though the sand is not absent. These various members may occur in any part of the region, but the sandier members are more prevalent just east of the Connecticut Valley basin than elsewhere.

The most important and permanent agriculture in southern New England, aside from the Connecticut Valley basin and the market-garden areas around the large cities, has developed on the Gloucester soils, and in both States they are the leading apple soils.

The Bernardston soils are an upland series closely associated with the Gloucester soils. They are gray to bluish gray in the soil and subsoil. The dark color is due largely to the presence of small particles of the dark-gray slate from which the soils are derived. They are usually heavier than the other series as a whole. Grasses both for hay and pasture do well on these soils. They occur in a number of places in the western part of the region, the type locality being near the village of Bernardston, Mass.

The Whitman soils are dark gray to black in color, with gray to yellowish mottled subsoils. They occur in depressions or on flat areas where natural drainage is not good, the mottled subsoil being due to this. They are derived from the same rocks and by the same processes as the Gloucester soils, but differ from them in drainage and aeration. These soils are more prevalent in eastern Massachusetts than elsewhere. If drained, they would be of value for grass, corn, and some of the late truck crops, but they are not suitable for the tree fruits.

A group of soils, seemingly with restricted distribution and which has not yet been officially named, but which will be described here as the Essex series, includes soils that are dark brown to nearly black in the soil, with yellow to light-brown subsoils. They seem to lie intermediate between the Gloucester and Whitman. They are better drained and at present more productive than the Whitman.

The Merrimac soils are brown to yellowish brown, with yellowish-brown subsoils. They occur on flat surfaces and are due to the deposition of material from running water. They consist, therefore, of assorted material, often have porous gravelly or sandy subsoils, and are on that account deficient in moisture-holding capacity. Where the gravel bed is several feet below the surface they are not droughty. They occur most frequently and in larger areas east of the Connecticut River. They are the prevailing soils in the flat sandy and gravelly lowland belts and in the flat areas in the eastern and southeastern part of Massachusetts. They are not so prevalent in Connecticut as in Massachusetts, though they are found along most of the streams. They are not subject to overflow. The heavier members are productive soils, except those with very gravelly subsoils near the surface. They are usually free from stones, but are nearly always gravelly.

The Wethersfield soils are the predominant soils of the Connecticut Valley basin and the Pomperaug Valley, aside from the soils of the river and creek bottom lands. The soils of the sandy members are gray or yellowish gray, often with a slight salmon tinge. The surface soils of the heavier members of the series range from pale to deep salmon color. The subsoils are salmon, red, or yellowish red in color. They are all, except the sands, good soils, naturally productive. The region of their occurrence is well developed agriculturally.

The Middlefield series includes the glaciated Triassic sandstone and shale soils which are characteristically yellow or gray at the surface. The subsoils are usually yellow. The series is derived from the same geological formation as the Wethersfield formation with which it is closely associated, though the color contrast is strong. In places the soils are complexly intermixed.

There is another group of soils occurring on the trap ridges which have been derived from ironstone (diabase). They occur typically on Talcott Mountain and associated trap ridges. They are important fruit soils and for convenience in this report are referred to provisionally as the Talcott series. These soils have a rusty brownish-red surface with dull reddish subsoils, their structure differing markedly from that of the Gloucester soils, though they resemble somewhat the Mont Alto soils of Pennsylvania, which are also derived from ironstone. Loams and silt loams are the principal types. The ironstones consist of a series of concentric rings which not infrequently are so decayed that several layers may be peeled off readily with the fingers. These Connecticut ironstones are only now and then as red as those giving rise to the Mont Alto series, but grade from a very dull red to a rusty blue. The subsoil is usually lighter than the surface soil, but its definite structure makes the material at first seem stiff, though it crumbles readily in the hand.

The Dover soils occur only in the Berkshire Valley and its extension southward into Connecticut. They contain a considerable amount of limestone material in their composition, and are naturally productive where drainage is sufficient, but they are not as desirable for orcharding as the best Gloucester soils.

The alluvial soils are small in area except in the Connecticut Valley. Where associated with and derived from the Wethersfield soils they are called Hartford soils, and where derived from the upland soil materials they are called Ondawa soils. Where well drained they are productive.

It is evident from this enumeration of the principal soils of southern New England and their characteristics that they are not predominantly sterile soils, but, on the other hand, the soils themselves are as a whole at least moderately productive. Through the processes of their formation they are usually stony, a considerable part of the area has a rough surface, and on account of the geographic position of the region the staple grain crops and the crops adapted to a long growing season and a hot climate do not grow as well as in some other parts of the country. Where the land has been cleared of stones so that it can be cultivated, where the topography is smooth enough for cultivation, and where crops adapted to the soils, climate, and other conditions of the region are planted, satisfactory yields are obtained. The poorest soils for most crops are the very light ones, such as the sands and gravel soils. These do not constitute the predominant soils of the region. They probably have the smallest acreage of any of the soils. Sandy and gravelly soils are common, but they are for the most part the sandy and gravelly loams.

SOILS OF THE DIFFERENT SECTIONS OF THE STATES.

THE SOUTHEASTERN SECTION OF MASSACHUSETTS.

The general elevation of Cape Cod above sea level is from 10 to 100 feet, though west of Barnstable, toward Bourne, hills 200 feet high are not uncommon. Level areas of appreciable size are few. The position of the Cape in midocean, as it were, exposes her farms, especially north of the elbow, to strong winds which have caught up the sandy soil and blown it in swirls here and there, thus forming a succession of low hills, knolls, and hollows. Both elevations and depressions are small in area; hence the surface of the Cape, especially east of Barnstable, is hilly, notwithstanding the slight elevation above the sea.

Many of the hilltops are not covered with vegetation, and on them sand-carrying winds make impracticable the growth of any except the hardiest plants, shrubs, or trees. It is in the hollows and on protected hillsides that the crops are grown, and there also the farm buildings are usually located. For this reason a casual glance over the region reveals only a small part of the gardening and farming operations.

The soils of the hollows and protected slopes have not had the finer particles blown from the surface by the winds, and the accumulation of humus from decaying plant growth has left them generally productive, yet their small size and limited production, together with lack of transportation facilities or high carrying charges, have prevented any considerable development of farming interests to compete in general markets. The very important fisheries have constituted, moreover, the principal industry. Hence the chief agricultural problem has been to maintain a home, to grow all sorts of garden and farm crops for family use, and to grow feed for the necessary horses and neat stock. This is a very legitimate and proper development of the opportunities, in that home supplies have been produced, while a main industry (fishing) has been specialized.

The attractiveness of the Cape as a place of summer residence has brought there a large population during the warm weather. This has created a large and growing demand for garden produce, summer fruits, dressed poultry, eggs, etc., much of which is shipped to the Cape from the Boston markets.

On the best of the soils located as described above, namely, in the hollows and on protected slopes, there are many excellent opportunities to grow garden crops, small fruits, plums, peaches, summer apples, etc. The best soil types available for this purpose are fine sand and loamy fine sand, principally, though occasional areas of the fine sandy loam occur. Areas of compact medium sand can be used for early-season garden crops, and even the coarse sands bring remunerative return where so managed as to provide a good supply of humus. In wet seasons strawberries and the cane fruits also do well, but in dry seasons the fruit is too small, and by midsummer there is liable to be insufficient moisture to maintain a good growth of plants, thus weakening their vitality. The latter feature not infrequently is serious enough to lessen greatly the crop of fruit the following season. This is especially true on medium to coarse sands and sandy loams of loose structure. Of these some areas are made even more porous by the presence of fine gravel, which is likewise found to some extent with the finer grades of sand and sandy loam. Stony areas occur, but they are generally small in extent.

Hay for home use is cut principally from the marshes, of which some are salt and others fresh. From the latter the best hay is secured, while salt marsh overflowed intermittently yields a medium crop, and land daily overflowed the poorest crop.

West of Barnstable there are appreciable areas of soils somewhat heavier than those previously described. Light sandy loams, light loams, and even light silty loams are sometimes found. The subsoil of the uplands is principally stony fine sand, stony sand, or stony fine sandy loam. There are many areas, too, of light sandy surface soils compared to those nearer the point. Gravelly sandy soils also occur, but at the present time these are little used for farming.

Thus it is seen that few of the soils of the Cape are drought resistant and crops frequently suffer for lack of moisture. So characteristic is this tendency that every possible means should be used to conserve moisture. This necessitates not only a large supply of humus, but also very frequent cultivation. The last is now given by the best farmers, some of whom plan to give surface tillage at least weekly. Humus burns out of these soils rapidly, but notwithstanding this characteristic, a good supply must be maintained if good yields of the various crops are to be secured. Since little stock is kept the small quantities of stable manure available must be supplemented by the use of cover crops—that is, the greater part of the necessary humus must be grown. Red clover succeeds, likewise Canada field peas. Other legumes have not been tried to any extent, and it is not strange that the few spasmodic attempts with alfalfa in most cases have failed. Rarely has the land been brought to a condition of sufficient productiveness before sowing the seed to attain success with this crop. The vetches are promising and should be thoroughly tried. It is also worth while to test the early maturing varieties of cowpeas, such as the Whippoorwill and New Era, though these are doubtless less dependable in this climate than Canada field peas.

Scattered about the Cape are many low-lying areas upon which the great cranberry industry has been developed. No attempt was made to examine in a comprehensive way the soils of these bogs, but they are evidently miscellaneous in character, though probably more uniform in the large bogs than in the small ones. While this variation may have been brought about in part, or at least have been accentuated in some measure by the sanding of the bogs, their virgin condition must have shown wide range in the proportion of muck and sand of which they are largely composed. In fact the countless areas that have never been improved leave no room for doubt on this point. The assorting of the fine gravels and the sands as shown from the rim of some of the bogs toward the center marks the range of local sedimentation and in-wash. The surface soil of one bog examined is a light muck mixed with a great deal of sand, there being enough of the latter to constitute in some places a mucky sandy loam rather than a sandy muck. The subsoil is extremely variable, often differing widely in borings only 3 feet apart. Only in spots is the subsoil a black clay loam, and in most places the soil auger 3 feet long may be thrust down full length with little or no turning. A blue clay is said to lie underneath, but in the borings taken none happened to be encountered within 3 feet of the surface. The soil is well drained to a depth of at least 2 feet. The most serious feature is an intermittent layer of water-washed sand from 6 to 12 inches thick which is found in places at 2 to 10 inches beneath the surface. Not infrequently some peat is found in the lower subsoil. Many of these bogs not utilized at present for cranberries would produce timothy to advantage. In others onions might well be grown by installing drains. To mix thoroughly the different soil materials, subsoiling and deep preparation tillage should precede such cropping wherever the sands occur in beds. Otherwise shallow-rooted crops would be liable to drought injury.

In the southern half of Plymouth and Bristol Counties the topography, the soils, and the crop use of the latter closely resemble the conditions in northwest Barnstable County already described. The lowland areas constitute very important cranberry lands. The acreage of this crop could be increased, but it should be realized that competition with other producing districts, such as New Jersey and Wisconsin, is likely to become more keen than at present.

The soils of northern Plymouth, northern Bristol, and eastern Norfolk Counties differ from those of the southern half of the former counties principally in having a smaller percentage of sandy types of soil and in having a greater proportion of their area above the 100-foot contour. An important part of this section, however, including that occupied by the Eastons, the Bridgewaters, Whitman, and Brockton, approximates only 100 feet in elevation, and almost the whole section lies between 100 and 200 feet above sea level. The local hills, except where the soil is unfavorable, are suitable for orcharding. The surface soils include loams, sandy loams, and sands of various depths, with subsoils of sandy loams and sands. The color of the surface soil is brown to yellow, while the latter color is almost universal in the subsoil. The subsoils of loamy types are typically lighter than the surface soil, a characteristic which very often obtains in Massachusetts, especially in the eastern part. Gravel is not infrequently encountered, especially in the subsoils. Its quantity is sufficient in places to prevent boring very far beneath the surface, but in no place examined was it sufficiently compact to constitute a true hardpan, though it is often so designated in local parlance.

The lowlands of the Bridgewater-Brockton district often consist of heavy loams with retentive subsoil, and on such soils much of the farming has been done, especially that of milk and hay. Many of these lowland fields should be artificially drained. In a few cases this has been done, but there is great opportunity for an increase of the areas so improved. Such drainage would unquestionably pay where the land is not so rocky and stony as to increase to an unwarranted degree the cost of ditching. These soils are good for hay production, and the nearness to Boston markets and the low cost of carrying city manure back to the fields suggest a desirable use for these soils.

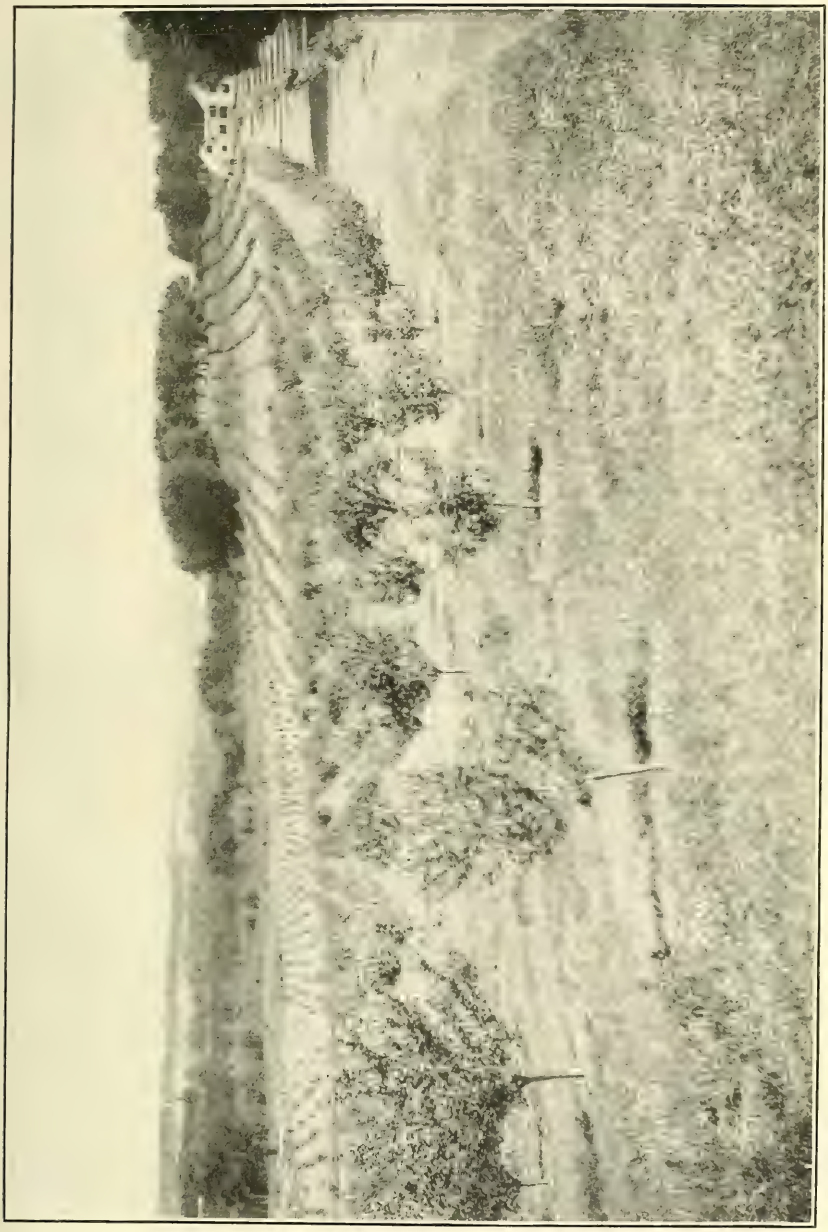
PLATEAU DISTRICT OF EASTERN MASSACHUSETTS AND SOUTHEASTERN CONNECTICUT.

Topographically, this district also includes much of Rhode Island, but the field work of this report did not include the soils of that State.

The average of the soils of this district in Massachusetts is somewhat more gravelly, sandy, and porous in the southeastern than in the southwestern part. In Connecticut the fine sandy loam is probably the predominating texture, most of the loam areas of Pomfret and Woodstock being in the Highland district. As detailed descriptions of the soils of this district may be seen in the detailed soil surveys of Windham County and New London County, they are not included here.

In Massachusetts the Blackstone River rises not far west of the city of Worcester and flows southeasterly to the corner of Worcester County. The Blackstone Valley is narrow and not particularly pronounced locally because of the broken surface features, but it is, nevertheless, a definite feature of the regional topography. The land is often stony and some of the lower areas along the stream are wet, so that much of the land is not farmed. There are some high terraces, however, as at North Uxbridge, where the surface soil of one considerable tract consists of open-structured fine sandy loam and light loam, with a few spots of fine sand. The subsoils in the same order are medium sandy loam, heavy sandy loam, and sand. These also are open structured, but as a rule not very leachy.

East of the Blackstone Valley in the Mendon section and extending thence north to Grafton, Hopkinton, and Sherborn, the land surface



TYPE OF PRESENT COMMERCIAL DEVELOPMENT.

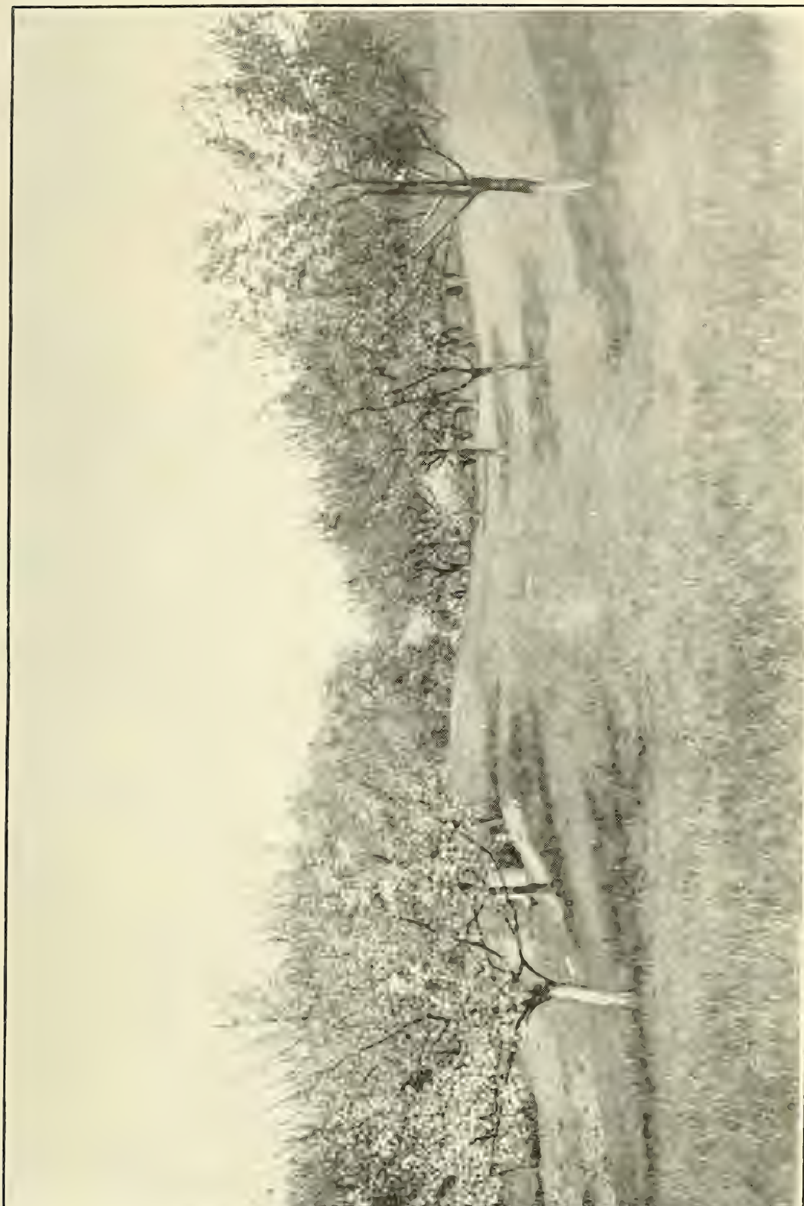
[Soil is the Gloucester stony loam, the stones and rocks having been cleared and dumped on low ground at left in middle distance. Fitchburg, Mass.]

FIG. 1.—MODERATELY EFFECTIVE SOD MULCH ON GLOUCESTER LOAM.

[The mulch should be a little heavier.]

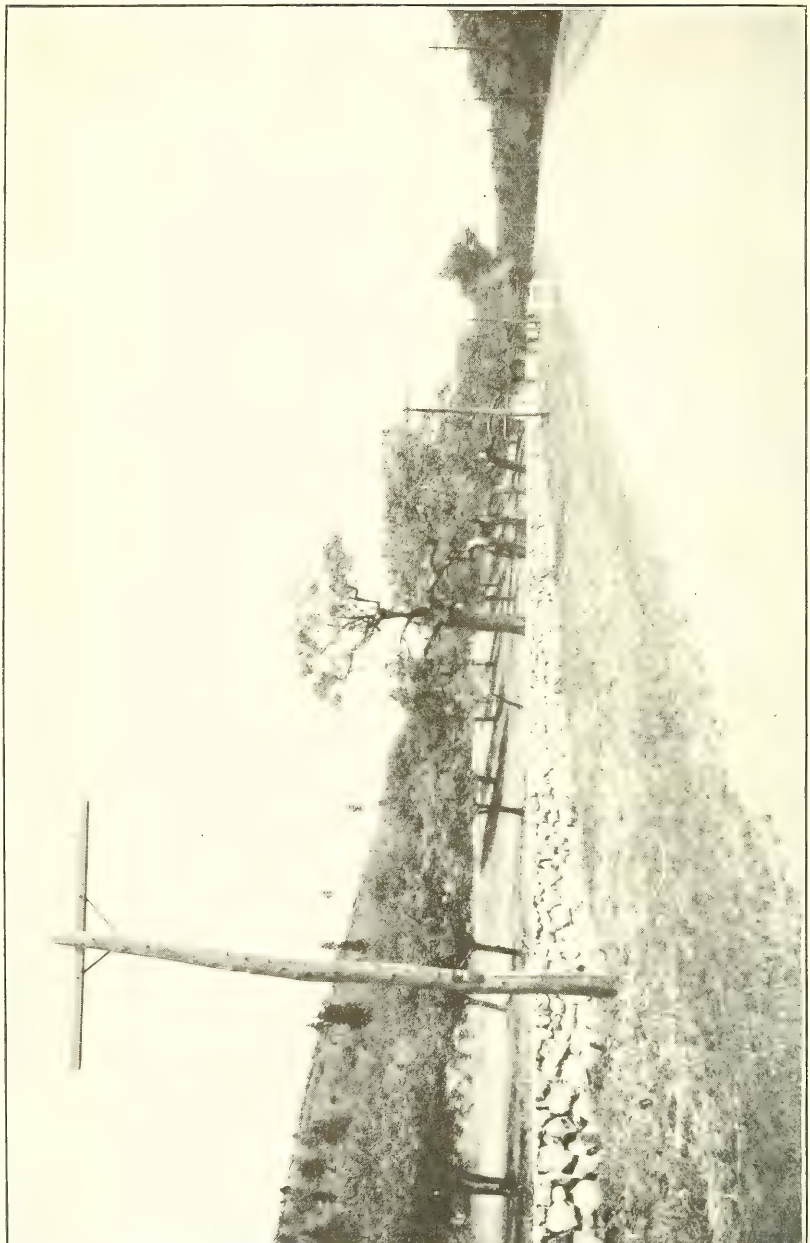
FIG. 2.—CUTTING DOWN FILLER PEACH TREES IN 5-YEAR ORCHARD OF APPLE STANDARDS.

[An unusual example of ability to carry out a purpose. Wallingford, Conn.]



APPLES A SUCCESSFUL MONEY CROP ON A DAIRY FARM IN THE BERKSHIRE HILLS, AT 1,000 FEET ELEVATION.

[Baldwin, 13 years old, on Gloucester loam. Crop rotation practiced in corn one year followed by grass about three years. Fertilized with both stable manure and chemicals.]



ROADSIDE PLANTING OF APPLES.

[Trees on right thrifty (see same in Pls. V and XX), but on the left undeveloped. Both lots cultivated when first set, but those on left have been owned by six different men and left in sod for last 20 years. Compare individual tree in Pl. V.]

is quite rolling, though the hills are not very high. Many of the hills are dome-shaped and afford excellent orchard sites. Their soils, too, are generally well suited to orcharding, often consisting of mellow, brown medium loams overlying a subsoil of friable sandy loam or light loam, yellow or brown in color.

Just west of the Blackstone Valley the land is more rough and stony until the general level of the uplands is attained, where it is moderately hilly westward to the French River.

Farther north in the town[1] of Sutton, where the apple of that name originated, the surface soils on a representative farm examined grade from heavy fine sandy loam in the "upper orchard" to a light silty loam in the "lower orchard." The subsoil grades from heavy sandy loam to light loam, and in places to silty loam. The color of the surface soil is brown and yellowish brown, and of the subsoil yellow, grayish-yellow, or light brown.

In North Grafton the surface soils in another orchard examined included loam, light loam, and sandy loam of brown or yellowish-brown color, while the subsoils consisted of yellowish loam and sandy loam. In large orchards of another farm were found the types above mentioned and also a heavier silt loam underlain by clay loam. In still another, a compact gravel layer was encountered at a depth of 2 to 3 feet. This condition is designated as hardpan, and while true hardpan undoubtedly occurs in spots, the term is often used in the State to indicate subsoil conditions much less serious than actual hardpan. These examples serve to show the local variability of the soils.

From the Sherborn-Hopkinton-Grafton district northward to Chelmsford and Groton the soils of the Eastern Plateau belt average a little heavier than in the southern part, though the total range in texture is just as wide. This district includes many prominent farming towns, and excellent orchards are frequently to be seen. Among these towns may be mentioned Shrewsbury, Northboro, Berlin, Hudson, Marlboro, Sudbury, the Actons, Concord, Stowe, Clinton, Lancaster, Bolton, Harvard, Littleton, Chelmsford, Westford, and Groton.

The most representative soils are loams and fine sandy loams. Silty loams are not infrequent, while now and then silt loams occur. The subsoils are seldom heavier than the surface soils, but are very often lighter. In some places the subsoil grades to a compact sand in its lower depths, and small gravelly areas are not uncommon. The well-drained and friable character of these soils has undoubtedly been a

[1] "Town" in New England is synonymous with township.

most important factor in the establishment of the numerous orchards. Most of these are small, to be sure, small orchards being countless, but there are also large plantings of both old and young trees.

The characteristic color of the above soils is some shade of brown or yellowish brown, but the heavier soils are sometimes grayish and the subsoils a grayish brown or gray. In some cases, but not in others, this indicates poor present drainage. It is evident that the grayish colors of some areas is due to deficient drainage before the land was cleared, the subsequent run-off of the surface and open ditches serving to bring the land to satisfactory condition for cropping.

The soil descriptions of the last district apply likewise to most of Essex County, though small areas of gravelly and sandy soils are perhaps a little more frequent, as are small areas of clay loams. In the Oldtown district, too, are some interesting loams carrying some well-developed orchards of Roxbury (*Roxbury Russet*). In describing soils for that variety these are classed as Essex loam.

North of Groton, and thence toward Hollis, N. H., a town just across the State line, there is another class of soil known locally as slate lands, and classed by the Bureau of Soils as the Hollis series. These have been derived from schistose rocks from which the "slaty" fragments in the soil have come. The soils are more moist than the corresponding types of the Gloucester series, and in crop use are similar to the Bernardston soils, being especially well-adapted to the production of grass and other forage crops. For the purpose of this report these soils may be grouped with the Bernardston series. The red varieties of apples do not color as well as those grown on the Gloucester soils, which on this account are more desirable for growing the red varieties.

North of the Merrimac River, and in northern Middlesex, northern Worcester, and northeastern Franklin Counties the topography is somewhat choppy, the soils are generally more sandy and porous, and farming is not extensively developed; and while sections of good farming lands and many good individual farms occur, the percentage of stony land is greater than in some parts of the Eastern Plateau of the Eastern Highland districts.

Land prices in the Eastern Plateau district are extremely variable, the average being much higher in Massachusetts than in Connecticut, largely because of the density of the population. Near towns and population centers, farm lands in Massachusetts are worth from $50 to $150 an acre, except in especially desirable locations, where they are much higher. At a distance from town land may be bought for much less than $50 an acre in both States.

THE EASTERN HIGHLANDS OF MASSACHUSETTS AND CONNECTICUT.

The upland soils of the Eastern Highlands are derived directly from glacial material. No exception to this was noted, and the glacial till is, for the most part, deep, even the hilltops having a thick mantle. The Gloucester series is by far the most extensive, but the Bernardston series is of importance in some localities. A striking feature is the stony character of the lowland soils. In this respect central Massachusetts, including much of the Eastern Plateau Belt, seems to differ from the glaciated districts west of New England, where the upland soils are generally more stony than the lowlands. In Worcester County and in places in eastern Massachusetts it is not unusual to find the lower-lying areas, which the railroads for the most part traverse, so stony that no attempt is made to cultivate them. Such lands were first cleared and used probably as pasture and then allowed to grow up in brush, a condition which now largely prevails. That such lands are not tilled leads the casual traveler to think them so unproductive as to be sterile or nearly so. An examination reveals good soils in many cases to be so stony that it is not practicable at present to put them in condition for cultivation. There are exceptions to this statement, of course, and some areas would become profitable if, the stones having been removed, they were artificially drained. Drainage, in fact, is an important problem in Massachusetts and to some extent also in Connecticut, and some time in the future many drains will be installed. Areas are not infrequently found that lack only drainage to permit profitable farming.

In much of Worcester County the largest areas of cultivated land lie on broad hills. The cultivated area often extends down a gradual slope or in other cases terminates abruptly as a sharper slope is approached. There is no uniformity in the selection of the areas for cultivation. The lay of the land even leads one to wonder why brushy fields adjoining those cultivated are not likewise tilled. An examination shows that some are as desirable for tillage and some of them even more so than the lands already farmed. Other areas of identical superficial appearance, however, show the good judgment of the owner in making no attempt to till them because of the stones.

The value of these lands or lack of it has had little to do apparently with their present use. Good lands were just as liable to be abandoned as poor lands.

That part of the Eastern Highlands extending from a line drawn from Leominster, Mass., through Princeton and Barre south to include Charlton and Warren, and also Woodstock, Pomfret, and part of Putnam, Conn., constitutes a good farming and orcharding section. Between Barre and Warren, Mass., this area should be extended westward to include the excellent town of Hardwick, to which reference has already been made. Yet even this locality has been improved and reasonably developed only in spots. From much more of the land is the production of crops and other farm products destined to be greatly increased and conditions are already ripe for the undertaking. Similar conditions obtain in the Pomfret-Woodstock section in northeastern Connecticut.

Good glacial loams, both medium and very heavy, produce good yields of corn and grass, the former being preferable for corn and the latter for grass. Both crops brought heavy yields in 1911, notwithstanding the droughty conditions that prevailed during much of the growing season. The medium and light loams are well adapted to orcharding, thrifty orchards here and there attesting to this fact, but they likewise are bringing good yields of forage for the production of market milk. Directly west from New Braintree, Mass., and toward Enfield the soils are more sandy, as they are to the southward in Hampden County east of a line connecting Three Rivers and the town of Hampden. These lighter soils also extend farther south into northern Tolland County, Conn., but in the southern half of that county the percentage of loamy areas increases somewhat.

Prescott, Mass., may be taken to represent one of the more undeveloped towns of eastern Hampshire County. Though hilly, this town has a sufficient area of soils that are capable of bringing good crops to warrant a much higher degree of farm improvement.

In northwestern Worcester, in the eastern parts of Franklin and Hampshire, in the southwest corner of Worcester, and in the southeastern part of Hampden County, Mass., and in northern Tolland County, Conn., the percentage of improved land is much less than in central Worcester County. Conditions differ somewhat, but the production of farm products is much lower than it should be. The elevation is high, the region is hilly, there is a considerable percentage of sandy and stony soils, distance from shipping points is relatively great, transportation over the existing highways is expensive, and hence large areas are in forest. Yet notwithstanding these adverse conditions, which are found in greater or lesser degree in most of the Eastern States, there are sufficient areas of good soils so located that they are easily capable of supporting a prosperous agriculture.

From the crest of the Eastern Highland to the Connecticut Valley there is a general slope, but its surface has been so dissected as to leave little semblance to anything plainlike. On the contrary, bold hills approximating 1,000 feet in elevation extend nearly to the Connecticut River, in the northern part of the State, near the Vermont line in east Northfield, and thence southward these high hills extend through the towns of Erving, Montague, Leverett, Pelham, and Enfield. Near the southern boundary of the town of Enfield the relief becomes much lower, and thence to the Connecticut line and far into Tolland County, Conn., the country spreads out into a succession of lower hills which are comparable to and connect with the eastern Hampden district. Much of this section is from 500 to 700 feet above sea level, though elevations up to 1,000 feet occur. The relief is characteristically much more gentle than that of the higher section to the north. The soils of the whole district are complex, often varying widely in short distances. They do not differ in kind from the rest of the Eastern Highland soils. but the percentage of sandy and porous areas is somewhat greater.

A description of the soils of a cross section from near the center of this north and south belt in Massachusetts follows: From East Leverett to within 1½ miles of Shutesbury the soils are extremely poor, being thin and sandy with some gravelly and leachy areas. Some of this material would have to be mapped as stony sand, the grades of sand being rather coarse. Formerly attempts were made to farm this section more or less, but the lack of adaptation of these soils to the production of the general farm crops which were tried necessitated their abandonment for that purpose. East of this belt, beginning about 1½ miles west of Shutesbury and including all of Shutesbury Hill from 1½ miles north of the center to 1½ miles southwest of the town much of the land should be farmed. Some of the soils of this district are heavy loams, with subsoils usually a little lighter than the surface soil. These can be classed as rather moist soils and are well adapted to hay as a money crop. On soils not quite so heavy, such as light loams and heavy fine sandy loams, a good corn crop was grown in the season of 1911; in fact, it compared well with the crop secured in the Connecticut Valley the same season. The lighter soils give good yields of potatoes, and this is grown as a money crop. The sandy loam types of the region are good for peaches, and with the light loams are hardly to be surpassed for the production of such varieties of red apples as are grown successfully in this part of the State. Such lands can be bought, without buildings, for $3 to $10 an acre.

The type of present commercial development in the section of the Eastern Highlands around Fitchburg is shown by the illustration, Plate I.

To the east of this belt there is a steep scarp to the west branch of Swift River along which there is another narrow belt of poor sandy soils. These, in turn, are succeeded by the more productive loams of Prescott Hill, already described.

THE CONNECTICUT VALLEY OF MASSACHUSETTS AND CONNECTICUT.

Walled in by the abrupt or broken slopes of the Eastern Highland

and the Western Highland, the productive and populous Connecticut River Valley is one of the most striking topographic features of Massachusetts and northern Connecticut. Approximately 2 miles in width in the northern part of Massachusetts, the valley broadens greatly about 2 miles south of Northfield Farms, where the river turns at a right angle and flows westerly toward Greenfield. There the valley is nearly 8 miles wide. Turning southward again, the river passes between Pocumtuck Mountain and Mount Toby. Together these mountains occupy about half the width of the valley. At the southern end of Mount Toby the valley steadily widens on the east side until it is crossed abruptly by a trap dike, the Mount Holyoke Range, which attains a height of 954 feet in the center of the valley at Mount Holyoke. Cutting through the range transversely the river pursues its way down through the central part of the main valley, leaving the southern extension of the Holyoke Range to the west. The latter turns directly south from Mount Tom, which is opposite Mount Holyoke, and, decreasing in height, forms a low divide far into the State of Connecticut. To the west of this divide is the valley of the Westfield and Farmington Rivers. The main valley continues about the same width to Hartford, below which it becomes narrower, is in part closed in, or is filled with dikes, and soon ends where the river breaks into the Eastern Highlands. Topographically it is succeeded by the New Haven Valley, which extends to Long Island Sound.

The alluvial and terrace soils of the Connecticut Valley are water sediments which have been deposited in currents of varying velocity. Near the present river the first terraces are most always silty, and silt soils extend for some distance up the immediate borders of the contributory streams. With increasing distance from the river, higher terraces were laid down when the stream was much wider than at present. These terraces consist largely of fine sandy loams, fine sands, and fewer loams. With increasing distance from the river the sediments become coarser until at the adjoining foothills coarse sands and fine gravelly sands prevail. The regular sequence of materials from fine to coarse has been often changed by the deposition of secondary valley streams.

The adaptation of the Connecticut Valley soils to onions and tobacco precludes their general use for orchard purposes. The tree fruits, furthermore, can be grown better on the hills, where land is comparatively cheap.

Viewed as a broad topographic and geologic division, the Connecticut Valley Basin includes not only the valley proper, but all the above-mentioned mountains within it and the foothills adjoining the valley on both sides as far back as the red and yellow sandstone and shale formations extend. On these elevations are found the soils of importance for fruit growing, as far as the Connecticut Valley Basin is concerned. Some of the prominent locations are the eastern side of Pocumtuck Mountain in Deerfield, Taylor Hill in the town of Montague, parts of the Mount Pisgah district in Gill, Mount Warner in Hadley, and some of the lower slopes and elevations of the Holyoke Range. In Connecticut sites just as favorable occur along the Talcott and Higby-Beseck Ranges, and the many smaller elevations.

The soils of these elevations, and also those of the Westfield-Farmington Valley Basin, have been derived from the glaciated residuum of the Triassic red sandstone and pinkish conglomerates. They are grouped as the Wethersfield, the Middlefield, and the Talcott series in the order of their extent. As some of these soils have been more extensively developed for peach growing than those of the other series the most important soil types are here described in detail.

In Massachusetts the most common type in the Wethersfield series is the sandy loam, but the loam is also of importance. The surface of the former consists of gray, salmon, or pinkish-gray sandy loam or loamy sand from 6 to 10 inches deep. The subsoil is variable, ranging from a sandy loam to a silty loam. The latter usually contains enough medium or coarse sand to make it somewhat gritty, the grains of sand being sharply contrasted in color with the heavier red matrix soil materials.

The Wethersfield loam consists of red silty loam to an average depth of 8 inches. It usually contains enough medium sand to be somewhat gritty. The subsoil is a gritty loam or sandy clay loam. In Massachusetts most of the series is somewhat stony, and a good bit of it is very much so. In Connecticut this series is much better developed. The average texture is heavier, the silty loam occurring in extensive areas, and a much smaller percentage is stony. Thus the average productiveness is much greater in Connecticut than in Massachusetts.

The Wethersfield soils are normally a little less productive than the Gloucester series. This difference is greater, however, in Massachusetts than in Connecticut. Not only is the forest growth lighter, but the percentage of soft-wood varieties is greater. Grasses do not hold as long either in meadow or in pasture, and it is generally considered that tilled crops require a little higher fertilization. The soils are well drained and crops mature a little earlier than on the Gloucester soils. The sandy loam is a favorite soil locally for early potatoes. In Massachusetts peaches have been grown successfully in some instances, and there is a good opportunity for the extension of the industry, as the soil is well adapted to their production, and the areas have good local markets.

In the Middlefield series the range of types is about the same as in the Wethersfield series, so separate description is not given. It is a companion series to the Wethersfield, from which it is separated primarily on the basis of color, though there is some variation in the productiveness and adaptedness when some of the corresponding soil types are compared. These soils are of much less importance in Massachusetts than in Connecticut, where they support good orchards, and their adaptedness is closely comparable to the Wethersfield series, the difference being of type rather than of series.

In the Talcott series a silty loam and a silt loam are the predominating types, but in them the presence of small ironstone fragments makes the friability of the soil mass greater than it would otherwise be.

A soil map of the valley and the hills immediately adjoining was published in 1903,[1] so the valley soils will not be described further in this report.

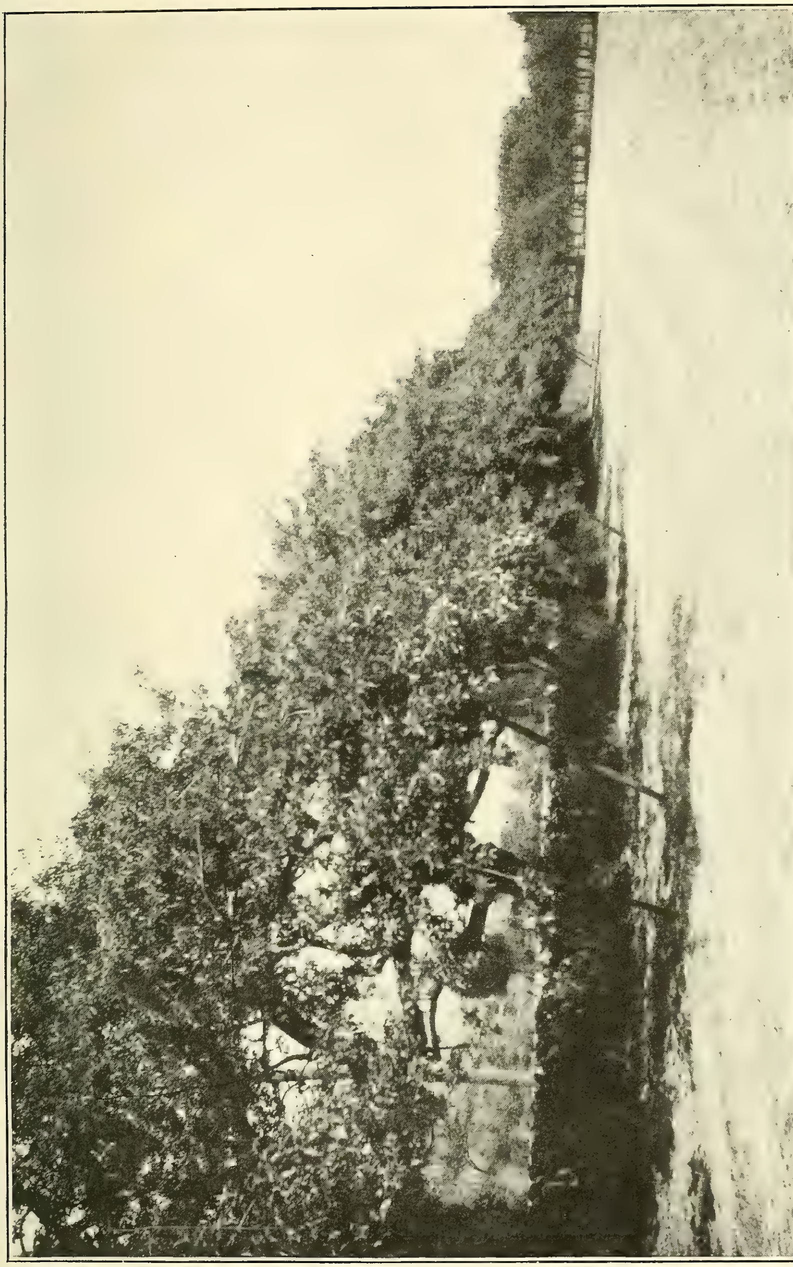
THE WESTERN HIGHLANDS OF MASSACHUSETTS AND CONNECTICUT.

From the Connecticut Valley the irregular surface of the western highland rises to the mountainlike crest of eastern Berkshire County for a distance of 20 to 30 miles. Across this easterly sloping plateau surface flows the Deerfield River in northern Massachusetts, the Westfield River in southern Massachusetts, and the Farmington River in northern Connecticut. All these are tributary to the Connecticut River. When the drainage of the western plateau becomes southerly the waters are carried chiefly in the Housatonic River and its important branch, the Naugatuck, though the Saugatuck River is also of importance. These rivers with their numerous tributaries have cut deep courses with fall sufficient in most cases to give rapid currents. Deep gorges are local characteristics, but the streams are usually swift even in the more prevalent open country. Between the stream cuts there are considerable areas of relatively smooth land, with medium-textured Gloucester soils.

Following the drainage basin of the Deerfield River westward from its junction with the Connecticut, the valley is dissected only to moderate depth in the towns of Shelburne, Conway, and West Deerfield, the adjoining irregular hills including much farming land, of which some is excellent.

In Charlemont, Buckland, Hawley, Florida, and Rowe dissection is much deeper, and with approach to the Hoosac Tunnel it is steep

[1] Soil Survey of the Connecticut Valley, Field Operations, Bureau of Soils, 1903.



SECTION OF ROW ON RIGHT IN PLATE IV.

[These trees are 96 years old and in 1910 yielded 100 barrels from 26 trees. Soil is the Essex loam. Compare individual trees in Pl. XX.]

FIG. 1.—WILD APPLE THICKET IN FOREGROUND, IN A LEYDEN PASTURE, BEING THINNED FOR GRAFTING. COLERAINE DISTRICT.

FIG. 2.—A DETAILED VIEW OF FIGURE 1.

[Taken after the grafting had been begun.]

or even precipitous. The valley of the Deerfield is not very wide after it enters the western highland, but in many places narrow bands of alluvial or high-terrace soils are well farmed.

On both sides of the Deerfield Valley, extending back for many miles, are hill towns with considerable areas of smooth land. Some of these already have good agricultural records for their output of farm stock and orchard products, and others seem worthy of further development. Even the best developed of these towns have made little more than a beginning, however, on the upbuilding of their opportunities. Of this broad section of good agricultural soils no general boundaries may be drawn, though the following-named towns are representative of the belt: Shelburne, Coleraine, Leyden, Heath, Charlemont, Buckland, Conway, Ashfield, Cummington, Worthington, and part of Plainfield.

It seems probable that the small amount of lime entering into the composition of some of the rocks from which the Gloucester soils of this section have been derived is partly responsible for their productiveness, which is apparently a little greater than that of the Gloucester soils of the Eastern Highlands, where lime does not seem to be present in the rocks. This comparison applies just as well to Vermont (the State where the mountains are green) and to New Hampshire (the State where the mountains are white), the latter corresponding to the Eastern Highlands and the former to the Western Highlands.

Three general soil types cover the principal areas of the best farm lands of this district. Of these, the Gloucester loam, a brown, mellow, medium loam, with subsoil of yellow or light-brown loam or light clay loam, is especially noticeable. This soil is naturally well adapted to the production of corn and clover, and when well handled gives excellent returns with these crops. A companion type, the Bernardston loam, consists of a very heavy loam, which is somewhat moist, and of grayish-brown or grayish-black color. The subsoil is gray or grayish. This is the best timothy soil of the region, and on it pasture grasses hold for a long time. As much of the type would be improved by artificial drainage, however, it will be recognized that this soil is not as well adapted to the clovers as the preceding type. In its present condition a good deal of this kind of soil needs lime. The third type, which is representative of the lighter soil areas, consists of a fine sandy loam, with a subsoil of loam, fine sandy loam, or sandy loam. Its area is much less than that of the two preceding types. All of these soils contain stony areas, some being so stony as to interfere with tillage, or at least to increase its expense.

Interspersed with the prevailing soil conditions described are many local areas of rougher topography. These include slopes to stream courses as above mentioned and also scattering sharp hills and ridges, from which slow, yet long-continued, erosion has removed considerable parts of the soil mantle. Most areas of this sort are stony, while some of them are very much so, and ledges often protrude. Along the latter the depth of the soil is far from uniform, as the tilt of the ledge plain varies all the way from nearly horizontal to perpendicular.

As "Apple Valley," in the towns of Ashfield and Buckland, has earned a somewhat noted and well-deserved reputation for its orchards, the character of its soils are of special interest. The soils range from light loams to heavy loams and clay loams, the textures of the subsoils being similar in range. The soils are all derived from deep glacial till. Some fields are comparatively free from stones and others are very stony, but most of the valley is moderately stony. The soils are productive, but the men of the section must be given credit for having used them skillfully. Soils as good for orcharding and farming occur in various places in the hill towns of western Franklin and western Hampshire counties that should be equally developed.

Orchard and farm lands can be bought in the Western Highland section of Massachusetts for $10 to $30 an acre, and on tracts of 100 acres or more very good farm buildings are often included at the latter price. Farms of 100 to 150 acres with good buildings are to be had for $5,000. These prices can be duplicated in western Connecticut, except where the purchase of farms by outside residents has led to a marked increase in prices. This applies more especially to the southwestern part of the State.

In the southeastern part of the Western Highlands in Massachusetts and in the northeastern part in Connecticut dissection has been very deep, especially in the towns of Russell, Blandford, Montgomery, Chester, and Huntington, where the slopes above the channel of the Westfield River are exceedingly steep, broken, and rocky, and in those towns of Connecticut along the break in the highlands toward the Connecticut and Farmington Valleys. Local areas are sometimes too rough even for feasible forestry planting, yet here and there are smooth, rounded hills or moderate slopes of sufficient area to afford good sites for orchards and other crops. The soils of one large tract examined in western Hampden County included loams—heavy, medium, and light—the subsoils rarely being as heavy as clay loams. Traces of hardpan sometimes occur, but suitable areas free from this difficulty are readily found. Spouty and seepy slopes, which are sometimes encompassed in desirable fields, it is practicable to drain artificially.

That part of Hampshire County between the Connecticut Valley and the upper Westfield River Basin is much less deeply dissected than the section traversed by the latter river, though withal it is hilly. The soils include a much larger percentage of sandy types than the Coleraine-Cummington region, but there are many good farming areas. Between Cummington and Northampton the loamy soils of the former town extend approximately to Swift River, east of which the soils are more sandy nearly to Williamsburg, and farming is less developed. A mile or two west of Williamsburg begins another strip of loamy and more productive soils, which extend to west Whately, southeastern Conway, and on to Patterson Four Corners. The road from Whately village north to Whately Glen indicates the eastern limits of this area.

In the Western Highlands of Connecticut, especially west of the gorge of the Naugatuck River, where dissection and erosion have been more kind than farther east, there are many good farming towns, especially in Litchfield County. Not all localities were examined in detail, hence various good towns were doubtless missed, but among those seen may be mentioned Canaan, Cornwall, Litchfield, Washington, Woodbury, Western Watertown, and Southbury in New Haven County, and Newtown, Redding, and Ridgefield in Fairfield County.

Passing northward to the foot of the Hoosic Range in northwestern Massachusetts, the soils up the eastern slope are much more sandy than those of the lower highlands. Going through the tunnel of the Boston & Maine Railway, in Hoosic Mountain, one approaches North Adams, which is located near the center of the Hoosac Valley. There the North Branch, flowing from Vermont, joins the Hoosac River as it comes from Berkshire County and flowing westward through the defile between the southern end of the Green Mountains on the north and Graylock on the south, passes out of the northwest corner of the State. The valley of the Hoosac is flanked on the south in the town of Williamstown by a secondary rolling valley, in which are many good farms.

The greater part of the Hoosac Valley is occupied mainly by old glacial terraces, of which the soils include many areas of loam, but there are also many sandy and gravelly knolls and ridges. In the North Branch Valley in the town of Clarksburg the soils are very stony or even rocky, and their nearness to the good markets of North Adams accounts for the relatively high price of land—said to be \$50 to \$100 an acre, where within a radius of 4 to 5 miles from the town.

The soils of the Williamstown Valley average somewhat heavier. There are many areas of loam and clay loam, though sandy and gravelly knolls and low hills frequently occur. Good dairy farms are to be seen, the milk in excess of the local demand being shipped to Boston. Both Williamstown and North Adams are good local markets for considerable amounts of milk, cream, some butter, and much garden produce. There are few orchards, though good orchard soils occur on some of the local elevations.

The Upper Hoosac Valley towards Cheshire is narrow, being in places little more than a defile between Mount Graylock and the Hoosic Range. This is a general farming district. The valley closes in on the south with the low hills forming the divide between it and the Housatonic Valley. At Lanesboro the latter broadens and occupies nearly the whole of Pittsfield Town. It then divides, one arm extending south through the towns of Lenox and Stockbridge and the other arm southward through the town of Richmond to West Stockbridge. From the latter town to Housatonic village, mountains nearly close the valley, the spaces between them being occupied by narrow stream beds.

A few miles south of Great Barrington the valley is again nearly 5 miles broad, and thence it extends south to the Connecticut line, including a large part of the towns of Egremont and Sheffield in Massachusetts and of North Canaan, Eastern Salisbury, and Western Sharon, in Connecticut. The valley floor near the Connecticut line is about 700 feet, and at Pittsfield, Mass., about 1,000 feet above sea level. The Berkshire Valley is underlain by limestone and although the surface soils are glacial deposits, sufficient limestone débris has entered into their composition to render them somewhat more productive than they would otherwise be. They constitute the Dover series, and vary greatly. Areas of well-drained loams and some light clay loams are interspersed with more sandy soils. Some of the latter are susceptible to drought and general crops are not considered very safe, but the heavier soils are sufficiently retentive of moisture to constitute excellent grass lands. In some cases, to an extent, the soils are cold owing to inadequate drainage, and the crop yields are correspondingly low. Artificial drainage would pay on some of these fields and will undoubtedly be installed in due time.

The valley walls are generally steep, though here and there smoother areas open back into the adjoining hills. The hill region east of the valley includes many good farming localities, but generally speaking it is capable of much higher development. From Pittsfield south the valley is walled in on the west by abrupt hills which occupy the northwestern part of the town of Salisbury, Conn., and the towns of Hancock and Mount Washington in the southwest corner of Massachusetts, but farther north they pass out of Massachusetts and for some distance extend along the New York boundary, leaving room for a considerable area of good agricultural land in the town of Egremont. A representative sample of these good soils consists of dark-brown to dark grayish-brown medium to heavy loam to a depth of 9 inches. The subsoil consists of heavy light-brown or grayish-brown loam. These soils are mellow, deep, friable, and productive.

Land prices in the Berkshire Valley vary greatly, the highest prices current being due to causes outside of agricultural development. The attractiveness of the region has led to the establishment of many summer homes by wealthy urban dwellers, and a few remain throughout the year. The greater part of such transfer of real estate is congregated in a few towns (townships), and has greatly increased land values in the district immediately surrounding, but aside from such centers land prices are still very low.

Several points of soil condition favorable to orcharding in Massachusetts and Connecticut have been mentioned. These are: An abundance of deep, friable, well-drained, well-oxidized and sufficiently productive soils; the low price of such soils; and the nearness to the best of markets. Such soil areas are most frequent in the Western Highlands, the Eastern Plateau, and the Eastern Highlands. Several disadvantages should also be mentioned. Many of the upland soils are more or less stony, and in some cases rocky lands are frequently divided into fields too small for economic working and surrounded by stone walls, the removal of which involves some expense, and some districts are handicapped by their distance from railway shipping points. The minor lowland areas, outside of the Connecticut and Merrimac Valleys, often consist of sandy glacial terrace débris that is more seriously affected by drought than the upland soils, and normally less productive.

ORCHARDING; GENERAL CONDITIONS IN THE FUTURE.

An analysis of the agricultural resources of Massachusetts, including the soils, and the availability of excellent markets can hardly fail to lead to the conviction that a great deal of good land now bringing little return must eventually support very profitable lines of farming. The tendency of the last quarter century to leave farm-homes somewhat distant from towns and social advantages, notwithstanding the excellent opportunities for money-making which such farms might possess, has been notable and marks a definite stage in the agricultural history of the region. The still better advised return to such of these lands as possess good possibilities is sure to come, for they hold good opportunities for those able to take advantage of them. But the higher development of these lands will be shaped according to their adaptation to produce crops and products under existing economic conditions, and to meet the demands of, and to take advantage of, the markets near at hand. Experience has already shown the futility of trying to compete with the Middle West in farm products for which the soil and field conditions of the latter are superior. Hence New England farmers should welcome such competition instead of regretting it, and meanwhile bend their energies to producing and marketing the higher forms of products for which their location gives them an advantage over any possible competitors. The normal increase of the population of the United States is sure to effect this development eventually, because the increasing price of foodstuffs will make it necessary to use the many kinds of soils for those crops only to which they are best, or at least reasonably well, adapted. In the following chapter the development of orchards on suitable soils, and the kinds of soil on which several of the different varieties of apples, peaches, and pears may be expected to give the best, or at least good, results is treated in some detail.

In regard to the relative importance of the personal factor of the orchardist himself, as compared with that of the adaptation of the soil, it may be said that a man who strongly likes to grow apples may grow very good ones in spite of adverse soil conditions, because he makes all other conditions of growth favorable. Similarly he who does not care for orcharding may not produce good apples, even though his soil be excellent, because he is not imbued with the interest in the subject which makes for success. Yet he who enjoys orcharding is most successful when the soil factor, as well as the other factors necessary for success, receives due consideration, and only those varieties are planted on any given soil which that soil is best adapted to produce.

A "stony" loam is often recommended as a desirable fruit soil. In fact it is one of the assertions most commonly heard in this connection. Many growers think there is virtue in stones for increasing or enhancing the value of a given soil for apple production. If a soil is too heavy (clayey) or too impervious it is made more pervious by stones, but in this case their effect is only that of an antidote to soil conditions otherwise undesirable. It is an easy matter, furthermore, to select soils free from stones, or practically so, that are equally pervious and desirable or even more so, and such soils would have an additional virtue in that they could be cultivated more cheaply. Any benefit from the disintegration and decomposition of the stones during the lifetime of an individual is certainly negligible. Hence, while stones may be advantageous in loosening a clay soil somewhat, just as they are disadvantageous to a porous sandy soil by lowering its moisture-holding capacity, they should not be considered, except as above indicated, a desirable attribute of soils to be planted in orchard. Much of the current belief that "stony" soils possess some peculiar advantage in their adaptability to orchard fruits has undoubtedly arisen from the success of many orchards located on stony hills. The facts that the soils were in a large number of cases friable, deep, and at least fairly productive, and that air drainage was excellent have apparently made less impression on the mind than has the stony appearance of the surface.

The fact that a soil is stony does not necessarily imply that it is productive, even though friable and deep. But if apples are to be grown with profit when competition is keen, as it is periodically certain to be, the soil must be productive, or at least capable of being economically brought to a productive state and so maintained. To this point too little attention has been given.

As to the adaptability of well-selected soils, the price of land, and good markets the opportunities for successful orcharding in southern New England are exceptionally good. To certain features of the business, however, attention should be called.

In the current rapid expansion of orchard acreage there is a strong tendency to reduce every project to a strictly commercial basis of large proportions. Hundred-acre orchards no longer cause surprise, as various individuals and companies operate several times this acreage, and many more very large projects have been begun. On undertakings of such magnitude is the cry of future overproduction chiefly based. There is no denying the probability that the average wholesale markets of the future will be materially affected by fruit from these extensive plantings. But the economic efficiency attained in the individual development of these orchards, and the grade of fruit marketed will be very important factors in determining the financial outcome.

The history of orcharding has shown, moreover, that extensive planting is spasmodic. High prices lead to such an increase of planting that prices are eventually forced down whenever a large percentage of localities in the whole country happen to bear a full crop because of favorable seasonal conditions. The high prices and extensive plantings of the last several years make it seem very probable that the crest of such a wave may be approaching, and that prices ere long will be lower. When such condition arrives the survival of the fittest is the universal law that applies. It is at this point that the importance of selection of orchard site, soil, and location with reference to markets or shipping facilities becomes most apparent. Adequate care after planting must be given in all cases, but it alone is not sufficient where competition becomes acute. Cheapness in production of fruit demanded by extensive markets determines the value of most orchard projects, and orchards that are deficient in these various attributes are soonest forced out of business. This is not taken to mean, however, that profitable orcharding may not be carried on by the general farmer when carefully done. The old time orchard must go, however, or be rejuvenated and given consistent care if it is to serve any purpose very useful in the economy of the farm. It must be admitted also that there are certain objections to the extremely large orchard. Many of the tender-fleshed and thin-skinned varieties which the best retail markets desire are not amenable to ordinary methods of handling. Skilled help can undoubtedly be secured in many cases, but it is exceedingly difficult through all the processes of care and attention to give all the orchard and all the fruit the personal attention which enables the individual grower of, say, 10 to 20 acres to secure the highest prices of special markets or of retail trade.

Another excellent opportunity of the present time is to bring the old orchards into good bearing condition as soon as possible. In this way a few very profitable crops may be secured before the larger orchards of recent and present plantings bear much fruit.

The diagram, figure 2, based upon estimates prepared by the State board of agriculture, so far as production is concerned, shows the relative importance of different parts of the State as apple-growing sections. In many of these towns important plantings have been made since the preparation of these estimates. Similar interest and activity in towns not included in these lists will bring them also above the 10,000-bushel minimum not many years hence. In the diagram (Fig. 2) the approximate location of these townships is represented by symbols. Surrounding areas—not townships—of relative but not necessarily equal production are indicated by a system of lines.

CULTURAL METHODS IN ORCHARDS.

It is not the purpose of this report to discuss orchard cultural methods beyond calling attention to prevailing practices.

The profitable peach orchards are almost always cultivated, and those most profitable are cultivated assiduously until midsummer, when an annual cover crop is grown. The crops used for this purpose are many—rye, buckwheat, rape, cow-horn turnips, crimson, red and alsike clovers, winter vetch, etc., being in common use. Rutabaga seed is often thickly broadcasted, the best roots being sold and the remainder left as a cover crop.

The best of the commercial apple orchards are also cultivated to midsummer and then laid by with some of the cover crops named above. The sod-mulch system is also practiced to some extent and gives very good results where the plan is consistently and thoroughly carried out. The most common difficulty with this method is the failure to apply sufficient mulch to prevent the growth of any grass or weeds within a circle which should extend for a few feet beyond

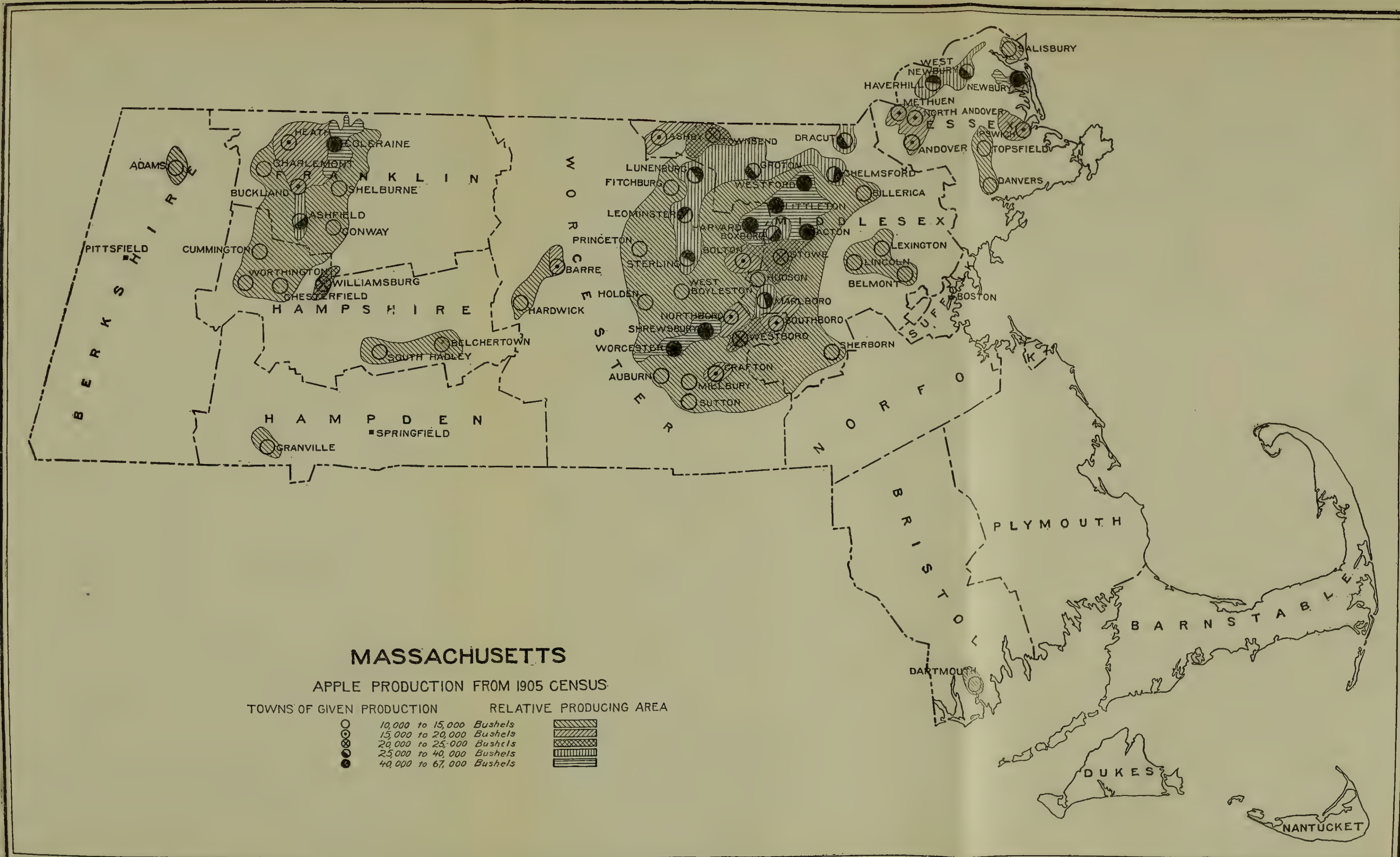


FIG. 2.—Relative importance of the apple-producing towns of Massachusetts.

the perimeter of the branches. In fact, the growth of grass just beyond the tips of the branches of a tree a few years old, or older, is far more serious than if near the trunk, where no feeding roots occur. Only by such thoroughness can mulching conserve even approximately as much moisture for the tree's use as thorough cultivation affords. Plate II, figure 1, shows a fairly good mulching, but even it should be a little heavier. Plate II, figure 2, shows there is at least one man who can remove peach fillers in time.

It must be admitted, however, that a large part of the aggregate number of apple trees in both Massachusetts and Connecticut regularly receive neither cultivation nor mulch. Of this great number of small orchards and miscellaneous trees some receive more or less cultivation when other crops are grown in the field where the trees happen to be, and in some cases the welfare of the trees is an important consideration, but more frequently it is purely accidental. Where the ground is well manured under the system of cropping followed—usually corn, oats, and grass in a 5-year rotation—very satisfactory results are secured. (See Pl. III.) A single row of apple trees along the fence or wall around fields (Pls. IV and V) is characteristic of many sections of both States, and from such trees very large quantities of fruit are produced, the aggregate being much larger in Massachusetts than in Connecticut. Many of the roadside trees were seedlings from which surrounding brush was cut away when the grafting was done. Often the grafting is not done until the seedlings are so large the scions are set in the limbs instead of in the trunk, with the result that the trees are usually headed 5 to 6 feet from the ground. The Baldwin is the variety almost universally used for this purpose. Most of the pasture trees were grown in the same way, though some are grouped around the cellar holes of former small farmsteads in the hills that do not now constitute economic farm units and so have been thrown into pasture. (See Pl. VI.)

There are thousands upon thousands of seedling trees in these States, with more annually springing up, that have not been propagated to improved varieties, although this is still a common practice in some sections, particularly in the Western Highlands. A large number of trees also occur in pastures where no cultivation or mulching is given. In this case the very close grazing of the grass by animals makes evaporation somewhat less than where hay is cut, and results are better than the careful orchardist would expect, but the method is to be recommended only where better methods are impracticable. This phase of orcharding also is somewhat more extensive in Massachusetts than in Connecticut. When results so good are obtained under such methods, the opportunities for the higher profits better care would bring are noteworthy. While similar roadside planting of trees is found in some of the noncommercial sections of New York, the custom is not so general there, nor are the results as a rule so satisfactory. In the heavy producing sections of New York large commercial plantings are the prominent feature, and the secondary plantings are of little importance.

The leading orchardists in southern New England use an annual application of commercial fertilizers in connection with a cover crop, or as a supplement to stable manure. Formerly mixed goods were used, but now many buy chemicals. There is much variation in the combination used. Basic slag is just now in popular favor and large quantities are used. Some acid phosphate is also used, but ground phosphate rock as a substitute is replacing it to some extent. Ground bone is preferred by some growers and tankage is in common use. The nitrates of soda or potash are employed as a source of ammonia when quick results are required. Potash is used in several forms—low-grade sulphate, high-grade sulphate, muriate, and kainit. The amounts used by different orchardists vary greatly and no attempt was made to cover the practice in a systematic way.

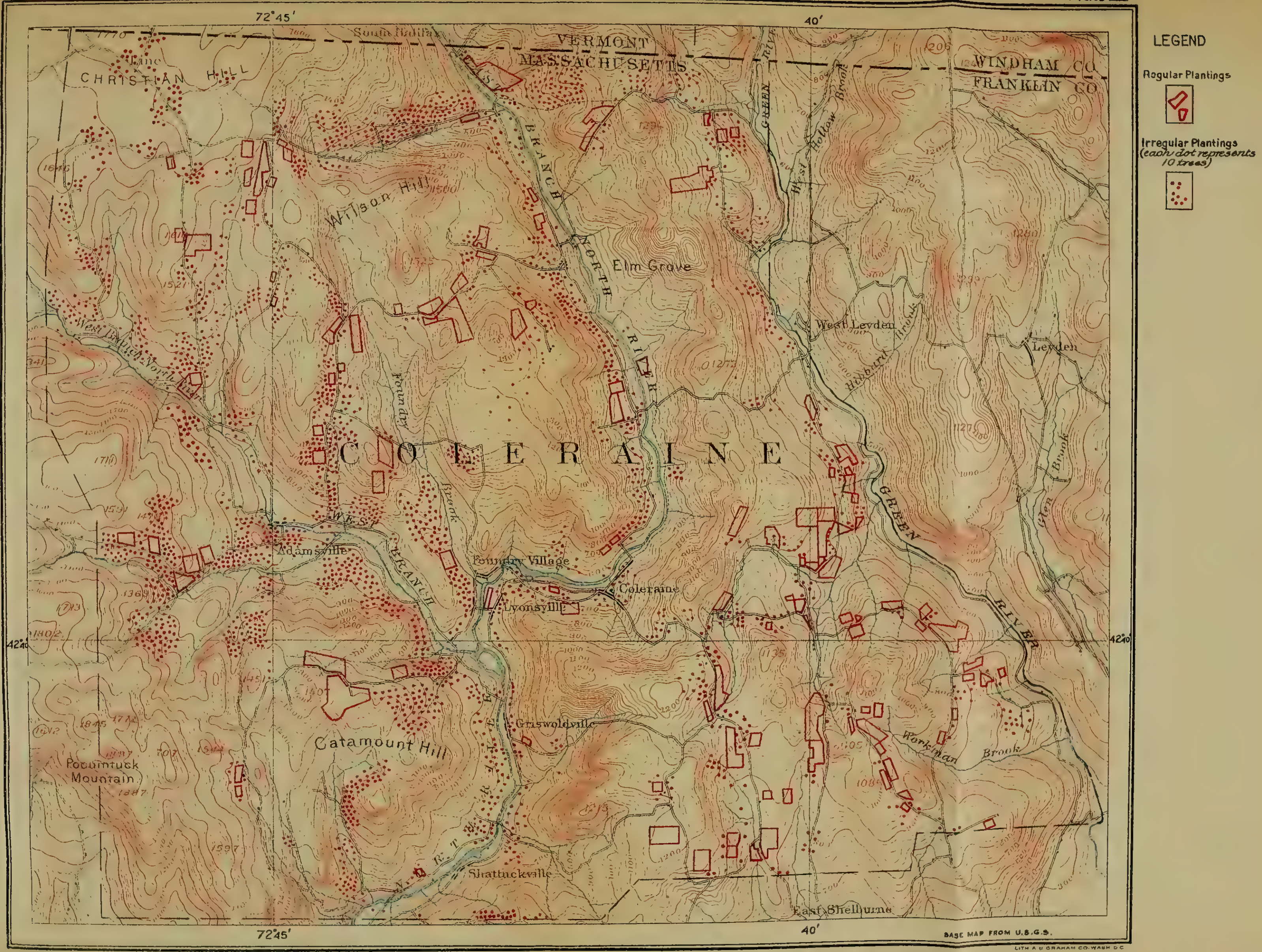
These different types of orchard distribution are brought out in Plates VII, VIII, and IX, which show the character of planting in Coleraine and Leominster, Mass., and in Parma, N. Y.

USUAL TYPE OF FARM-ORCHARD DEVELOPMENT IN MASSACHUSETTS AND IN WESTERN NEW YORK.

The character of orchard distribution in a town typical of central Massachusetts is shown in the map of Leominster. (Pl. VIII.) The western part of the town is so hilly and rough that there is little orcharding or farming. The rest of the town constitutes a good farming and fruit section. With general farming, some dairying, and a little trucking, apples are an important money crop in proportion to the land given over to orcharding, as appears in the census of production shown elsewhere, Leominster being in the group of towns that produce between 25,000 and 40,000 bushels of apples annually. There are no large commercial orchards, but there are a few of moderate size and many small ones.

On the sketch map the blocks of orchard are drawn to approximate scale and each dot represents 10 apple trees.

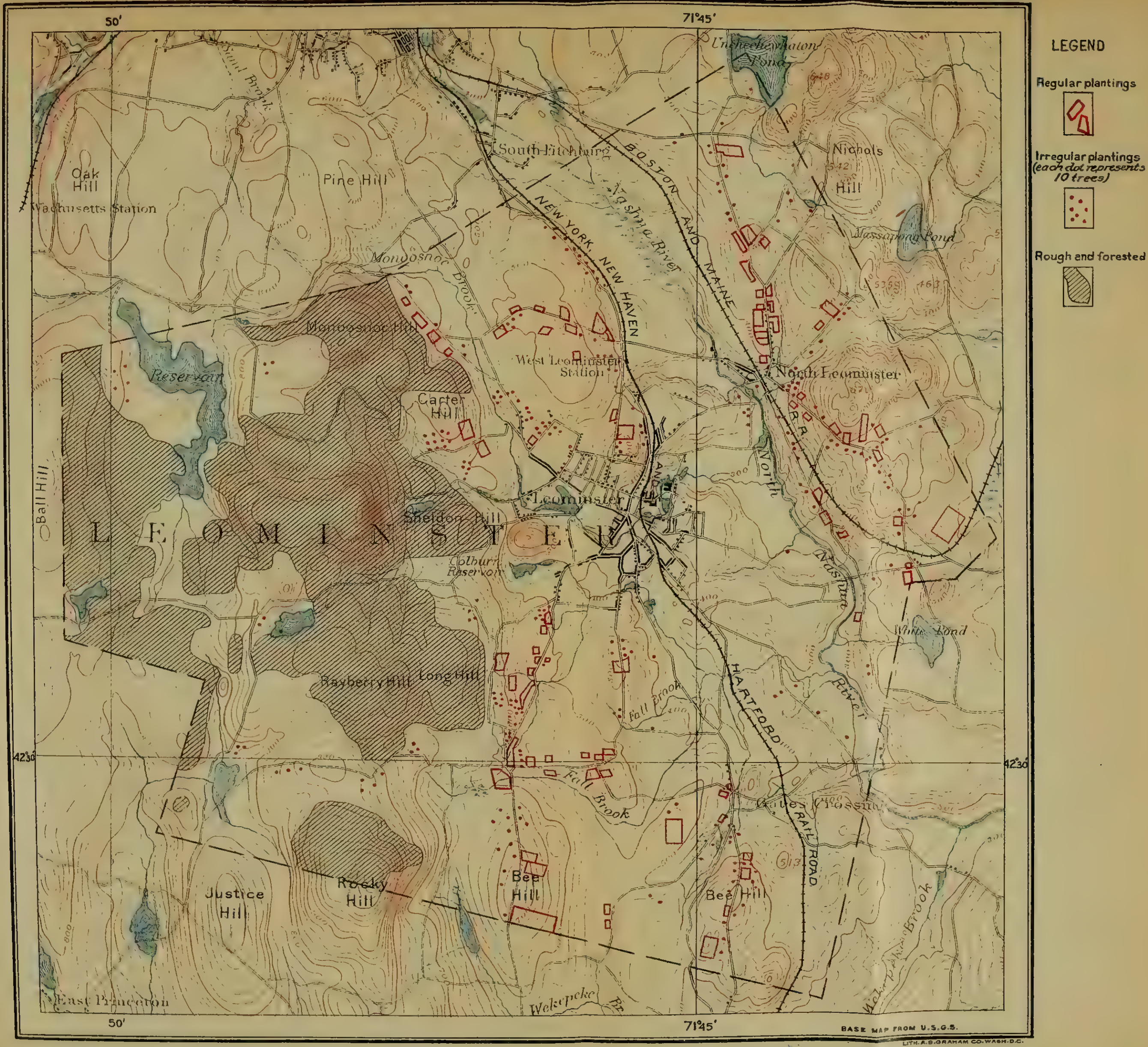
In parts of both States, but principally in Litchfield County, Conn., and that part of Massachusetts west of the Connecticut River, apples have long constituted an important money crop in conjunction with live-stock farming. Coleraine, Mass., is one of the



TYPE OF ORCHARD PLANTING FOR THE TOWN OF COLERAINE, FRANKLIN COUNTY, MASSACHUSETTS.

Scale $\frac{1}{62500}$

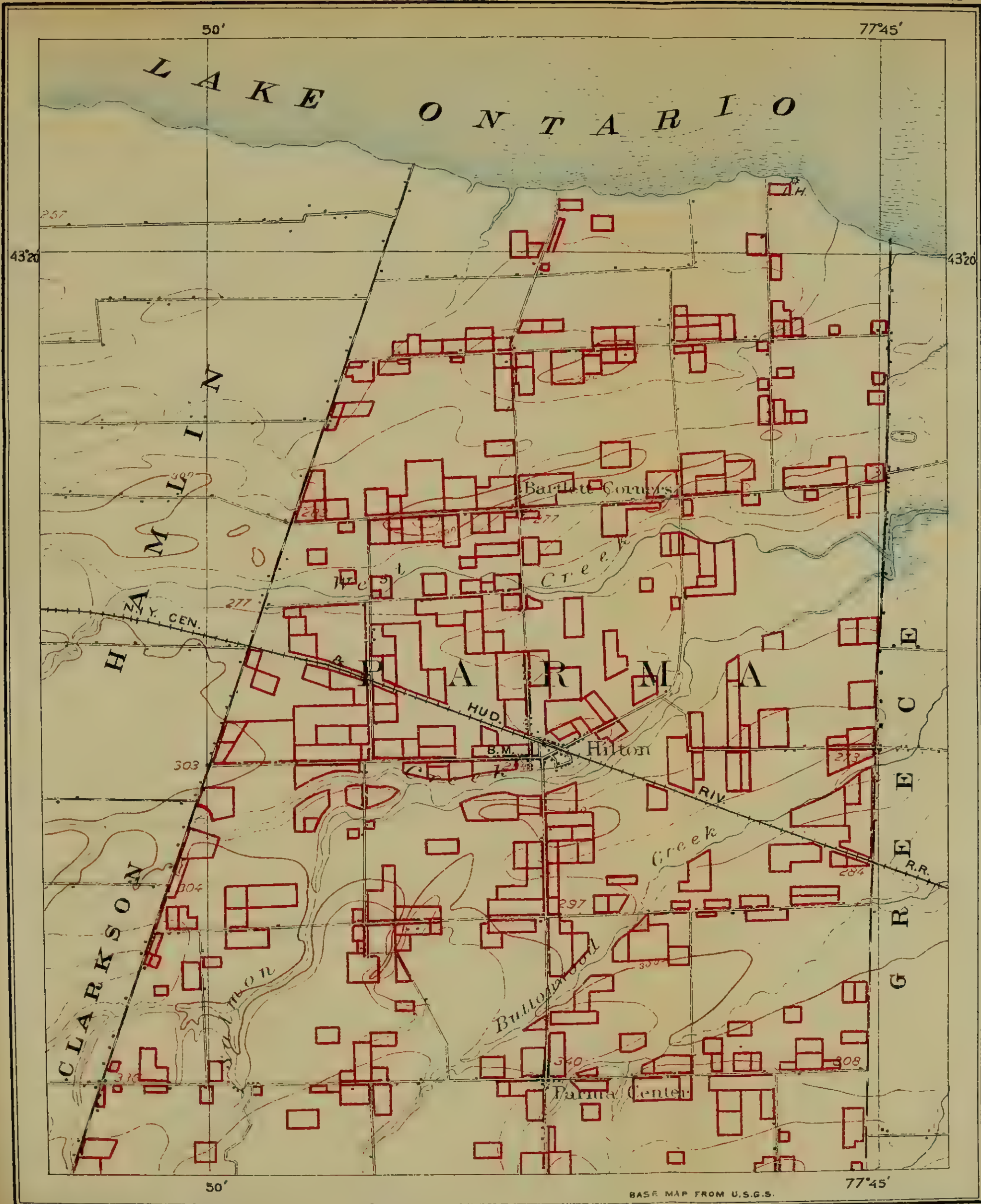
1 ½ 0 1 Miles



TYPE OF ORCHARD PLANTING FOR THE TOWN OF LEOMINSTER, WORCESTER COUNTY, MASSACHUSETTS.

Scale $\frac{1}{62500}$

1 ½ 0 1 Miles



LEGEND

Regular Plantings

TYPE OF ORCHARD PLANTING FOR PART OF THE TOWN OF PARMA, MONROE CO., NEW YORK.

Scale $\frac{1}{62500}$

1 ½ 0 1 Miles

prosperous towns of this class, and because of the intense development of this sort an orchard map was prepared to show conditions there. Definite blocks indicate for the most part trees grafted before they were planted or soon after, the trees being in regular rows. Orchards shown by dots have no regularity of arrangement. Of these trees the great majority have come up as seedlings where they now stand, and have been grafted as the owner could get to it or possibly hire some one to do it. A row of trees along a wall or fence surrounding tilled fields is a common feature, but probably more are located in pastures. Almost all grafting has been to Baldwin, no tree being considered too old for this purpose if in vigorous condition, though most of it is done before the trees are 20 years old. Five to ten years is considered a favorable time where the land is not to be grazed, as the scions can then be set high enough for teams to work underneath; but in pastures an older age is preferred so that cattle may graze without injuring the trees. Of so much importance are these irregular orchards that seedlings or nursery stock are not infrequently set in to fill any large gaps, thus by a little effort making a solid block of trees. This method of orcharding seems very strange to those unfamiliar with it; but the profits derived have been largely instrumental in the town's prosperity, and many Baldwins of exceptionally good quality are grown.

Countless thousands of seedling apple trees abound in Coleraine that are not yet grafted. Many farmers graft a few every spring as other work permits, or as outside grafters can be hired, but even so the number of trees is so great that many will never be grafted, notwithstanding the profit to be derived. It is doubtful if seedlings grow more profusely anywhere.

This system of orcharding, though unusual, is of much importance locally, and the profits derived are certain to lead to its steady development. From the ungrafted trees large quantities of cider are produced for vinegar, which constitutes no inconsiderable source of additional income.

RELATIVE PRODUCTION OF APPLES IN SOUTHERN NEW ENGLAND.

While it is often unsafe to draw definite conclusions as to the relative importance of fruit growing in different States, because of variations in weather conditions in any given year, age, and condition of trees, etc., such comparisons may nevertheless serve as a general index, and for this reason the figures below are taken from the United States census of 1910. It should be borne in mind that New York is by far the foremost State in the production of apples, having a greater yield than any other entire geographic group of States other than the one of which it forms a part; and in 1909 Michigan was the only other State exceeding Pennsylvania in the yield of this fruit.

Number of trees in orchards and production of orchard fruits in eight leading States for the years 1899 and 1909.

State.	Trees of bearing age.	Trees under bearing age.	Production.	
			1909	1899
			Bushels.	*Bushels.*
Massachusetts	1,698,220	591,796	2,763,679	3,158,781
Connecticut	1,369,515	604,296	1,874,242	3,839,105
New York	17,625,093	7,363,614	29,456,291	26,172,310
Pennsylvania	13,186,773	5,921,257	13,285,953	25,236,854
Michigan	12,842,827	6,679,949	15,220,104	9,859,862
Washington	4,944,889	6,951,251	4,244,670	1,180,357
Oregon	4,583,735	4,309,232	4,423,244	1,522,002
California	22,485,195	8,410,062	31,501,507	22,690,696

Number of trees in apple orchards, total production of apples in 1899 and 1909, and production per capita for the same years in selected States.

State.	Trees of bearing age.	Trees under bearing age.	Production.		Population, 1910.	Density of population per square mile, 1910.	Production per capita.	
			1909	1899			1909	1899
			Bushels.	*Bushels.*			*Bu.*	*Bu.*
Massachusetts	1,367,379	355,868	2,550,259	3,023,436	3,366,416	418	0.76	1.1
Connecticut	798,734	211,839	1,540,996	3,708,931	1,114,756	231	1.4	4
New York	11,248,203	2,828,515	25,409,324	24,111,257	9,113,614	191	2.8	3.3
New Jersey	1,053,626	519,749	1,406,778	4,640,896	2,537,167	337	0.5	2.4
Pennsylvania	8,000,456	2,501,185	11,048,430	24,060,651	7,665,111	171	1.7	3.8
Delaware	429,753	263,813	183,094	702,920	202,322	103	0.95	3.7
Georgia	1,878,209	822,327	895,613	670,889	2,609,121	44	0.34	0.3
Michigan	7,534,343	2,253,072	12,332,296	8,931,569	2,810,173	48.9	4.7	3.6
Illinois	9,900,627	2,548,301	3,093,321	9,178,150	5,638,591	100	0.55	1.9
Iowa	5,847,034	1,914,325	6,746,668	3,129,862	2,224,771	40	3	1.4
Washington	3,009,337	4,862,702	2,672,100	728,978	1,141,990	17.1	2.3	1.4
Oregon	2,029,913	2,240,636	1,930,926	873,980	672,765	7	2.8	2.1
California	2,482,762	1,054,107	4,935,073	3,488,208	2,377,549	15	2.6	2.3

Number of trees in peach orchards and production of this fruit in 1899 and 1909 in important States.

State.	Number of trees of bearing age.	Number under bearing age.	1909	1899
			Bushels.	*Bushels.*
Massachusetts	154,592	162,114	91,756	27,906
Connecticut	461,711	338,608	269,990	61,775
New York	2,457,187	2,216,907	1,736,483	466,850
New Jersey	1,216,476	1,363,632	441,440	620,928
Delaware	1,177,402	212,117	16,722	9,750
Pennsylvania	2,383,027	2,179,386	1,023,570	143,464
Michigan	2,907,170	2,991,090	1,686,586	339,637
Georgia	10,609,119	1,531,367	2,555,499	259,728
Washington	536,875	1,028,141	84,494	80,990
Oregon	273,162	508,179	179,030	101,190
California	7,829,011	4,409,562	267,118	8,563,427

Exports of apples from the United States at five principal eastern ports.

Port.	1912	1910
	Bushels.	*Bushels.*
Boston	437,611	170,013
New York	609,041	566,926
Philadelphia	649	39
Portland, Me	158,717	67,748
Baltimore, Md	168	92

The States of Massachusetts, Connecticut, New York, New Jersey, and Pennsylvania include approximately one-fourth of the population of the United States, and it is apparent from the above figures that Massachusetts and Connecticut are very fortunate not only in home markets for fruits but also in facilities for exporting whenever prices at home make it advisable to ship apples out of the country. These States have, however, an unusually large proportion of nonagricultural population, and local markets are exceptionally good in that they are well distributed and consume a relatively large quantity of fruit for which remunerative prices are paid. This gives no small advantage over States that have to ship a much greater distance to these same markets, but in order to take full advantage of these excellent opportunities the grading and packing of fruit should be greatly improved. There are already sufficient exceptions to inferior grading and packing effectively to demonstrate the superior profit of better methods, and by them the general grower should be guided. The importance of the fruit industry in southern New England necessitates a better development of business methods in handling and marketing the crop, and there is already a very noticeable and commendable tendency to effect these ends.

RELATION OF SOIL CHARACTERS TO CROP AND VARIETAL ADAPTATION.

While the statement that "a given variety of apple, for the most successful growth within its general climatic region, requires a certain kind or condition of soil" seems incontrovertible, inasmuch as it is so well substantiated by orchard results under a wide range of conditions, the reason why this should be so is not so easily stated. It seems to depend fundamentally upon the water-holding capacity, or rather the moisture coefficient, of the soil. The capacity of a soil to hold capillary water, which is the only kind plant growth can use, depends on (1) the soil texture (i. e., the size of the soil grain); (2) the soil structure or the grouping of these tiny grains into clusters, thus making it granular; (3) the amount of humus in the soil; and (4) the degree of soil tilth, which is a combined effect of the foregoing and tillage.

The film of moisture which surrounds every soil particle up to the point where saturation begins varies in thickness according to the amount of water contained at any particular moment by a given volume of the soil. The soil-film moisture is removed, not by drainage, but only by transpiration through growing plants and by evaporation. As the last factor can be held under control to a considerable extent by the dust mulch system of crop cultivation, or by artificial mulches, the amount of soil moisture available to growing plants and trees depends upon the film moisture contained in the soil, and the amount of this depends in the first analysis upon the texture of the subsoil and to a lesser degree upon that of the surface soil. As every soil particle is surrounded by a film of moisture, it follows that the finer the soil the greater is the number of films, and likewise the greater the area or amount of moisture in a given volume of soil.

Whitney [1] found that the surface area of the soil particles in a cubic foot of the subsoil in the pine barrens land was about 24,000 square feet, in silty and fine sandy river terrace subsoils the area was 100,000 square feet or $2\frac{3}{10}$ acres, and in the much more clayey limestone subsoils 200,000 square feet. In commenting on this data, Wiley [2] states:

> This great extent of surface and surface attraction gives the soil great power to absorb moisture, and thus the soluble mineral ingredients, of which most soils contain only a little, are held too closely to allow of rapid loss by drainage, and still sufficiently available to answer the needs of vegetation, provided the store is large enough.

And again:

> The porosity of a soil depends upon the size of the soil particles (texture), the way in which these particles are grouped together (structure), and upon the space between the particles or groups of particles. If a soil be cemented together into a homogeneous mass, its porosity sinks to a minimum; if it be composed, however, of numerous fine particles, each preserving its own physical condition, the porosity of the soil will rise to a maximum. The porosity of a soil may be judged very closely by the percentage of fine particles it yields on mechanical analysis. A finely divided soil has a high capacity for absorbing moisture and holding it. The adaptation of a soil to different crops depends largely on the sizes of the particles composing it.

This is illustrated in the case of a certain soil containing about 30 per cent of clay, "which is strong enough and sufficiently retentive of moisture to make good grass land, but too close in texture and too retentive of moisture for the production of a high grade tobacco or to be profitable for market vegetables."

Cameron and Gallagher [3] found that the optimum moisture content—i. e., the particular content at which a given soil can be put into

[1] Whitney, Md. Agr. Expt. Sta., 4th Ann. Rept., p. 282.
[2] Agricultural Analysis, pp. 131–132.
[3] Bul. 50, Bureau of Soils, U. S. Dept. of Agr.

its best possible condition for plant growth—varies widely with soils of different textures. In other words, from a given amount of rainfall one soil is more capable than another of furnishing optimum moisture to a given crop. Frear[1] states that—

> Equally essential with the proper food supply for the growth of a crop are fitting temperature, moisture, and looseness of the soil for the root of the plant. While the soil temperature and moisture are strikingly affected by local climate, they depend also in very large measure upon the structure of the soil itself. If we could determine the structure of the soil accurately, we would probably be able ere long to make quite exact predictions as to the kinds and qualities of crops any soil whose structure was known could produce. * * * While no satisfactory means have been devised for determining soil structure with precision, the size of the particles of which it is composed affords valuable indications of its physical properties and especially of its moisture relations. Another important function must be added: The soil largely modifies the climate to which the plant is exposed. We are accustomed to regard atmospheric conditions as most largely influencing the life activities of plants, but careful observation has shown that within a wide range of temperature the warmth of the soil far more than the air determines the vigor of plant development.

With tillage conditions equal, the thickness of the film of moisture around each grain of soil depends, on the one hand, upon the supply of ground water at any particular time, and on the other, upon the rapidity with which the film of moisture is being removed by plant rootlets. Amendments may be added to the soil in the form of lime and humus, which also affect in varying degree the amount of film water in the soil which is available to plant rootlets. But the plant food in the soil is obtained by growing plants only as it is dissolved in the soil film moisture, hence it is apparent that the distribution and consequent availability of the moisture is a matter of the utmost importance.

Jeffery[2] found in his work on the water-holding capacity of soils that of water that was passed—

> Through 100 ounces of air-dry clay soil, 56 ounces were retained.
> Through 100 ounces of air-dry loam soil, 49 ounces were retained.
> Through 100 ounces of air-dry sandy soil, 36 ounces were retained.
> Through 100 ounces of air-dry muck soil, 170 ounces were retained.

In the first three cases the differences are due largely to the size of the soil grains. In the fourth case the great capacity of the soil for water is due to the large amount of organic matter present, which in this particular soil was over 69 per cent. It is thus apparent that any marked increase in the water-holding capacity of any one of the three first grades of soil in the above experiment would require some amendment, and for this purpose humus is the most efficient. In the case of the sandy soil, however, decayed organic

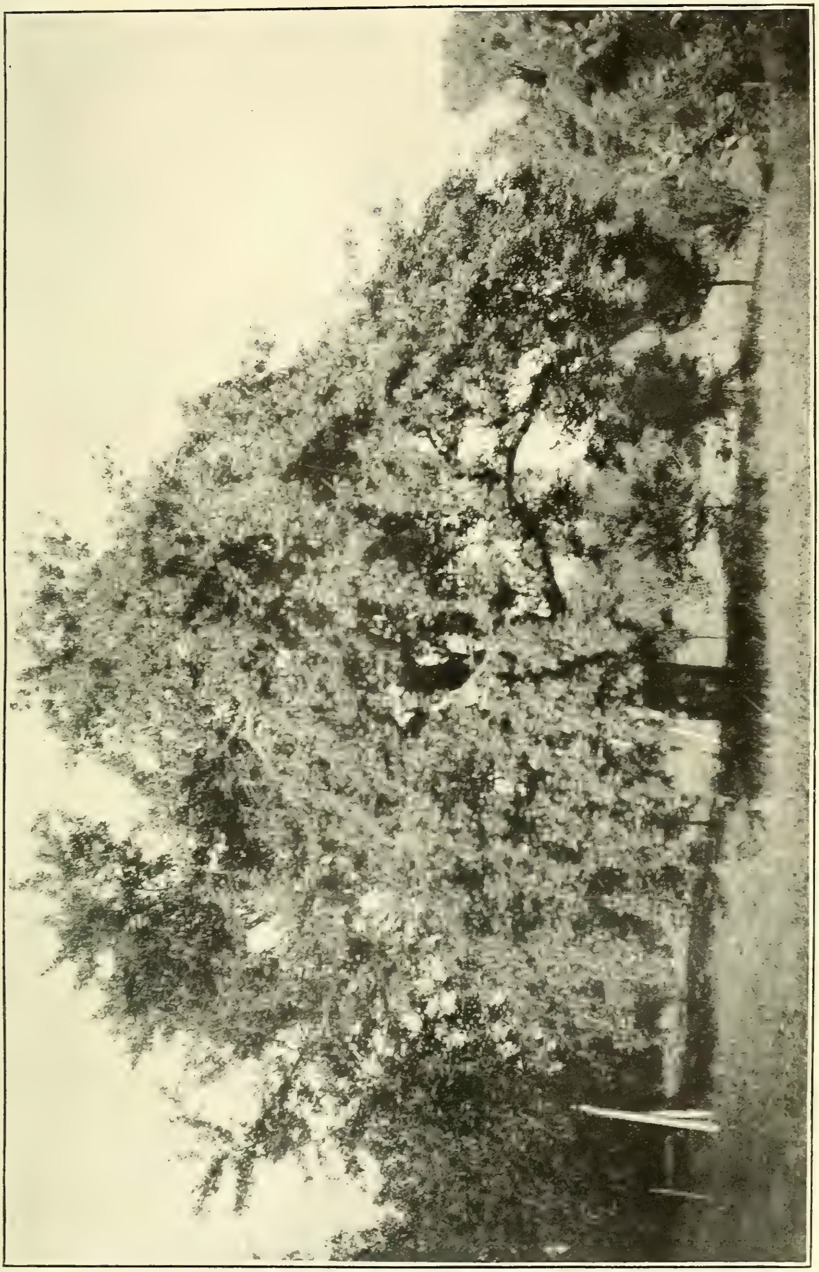
[1] Bul. 20, Pa. Agr. Expt. Sta.
[2] Bul. 219, Mich. Agr. Expt. Sta.

matter would be required in such excessive amounts as to upset the equilibrium of the fruiting and vegetative habits of the tree; that is, the sandy soil would actually become so "mucky" as to give an excessive vegetative growth at the expense of fruit yield, and an important percentage of the fruit obtained would be deficient in color. Humus is, nevertheless, the most important factor or agent, as the case may be, in modifying the physical condition of the soil mass so far as the mineral constituents are concerned. This it does by partly filling the spaces between the grains of sand, i. e., the coarse particles, and by holding apart the finer particles of clay. In these ways both sand and clay are made more loamy and favorable for plant growth. By increasing the number of particles in a given volume of soil, by helping to group the soil particles into clusters, thus increasing granularity, and also by actual absorption of moisture, humus increases the moisture-holding capacity of the soil and likewise the availability of the mineral fertilizing constituents.

To change, furthermore, by the addition of humus, the physical condition of a sandy soil to a depth reached by tree roots sufficiently to make its supply of available moisture the same as that of a heavier soil, such as a loam or a clay loam, is unquestionably an expensive process, even were it desirable; and orchards are grown for profit. Hence this phase of the whole problem is an economic one. It is good business to select soils naturally adapted to the different varieties, rather than to use soils that must be modified to make them suitable.

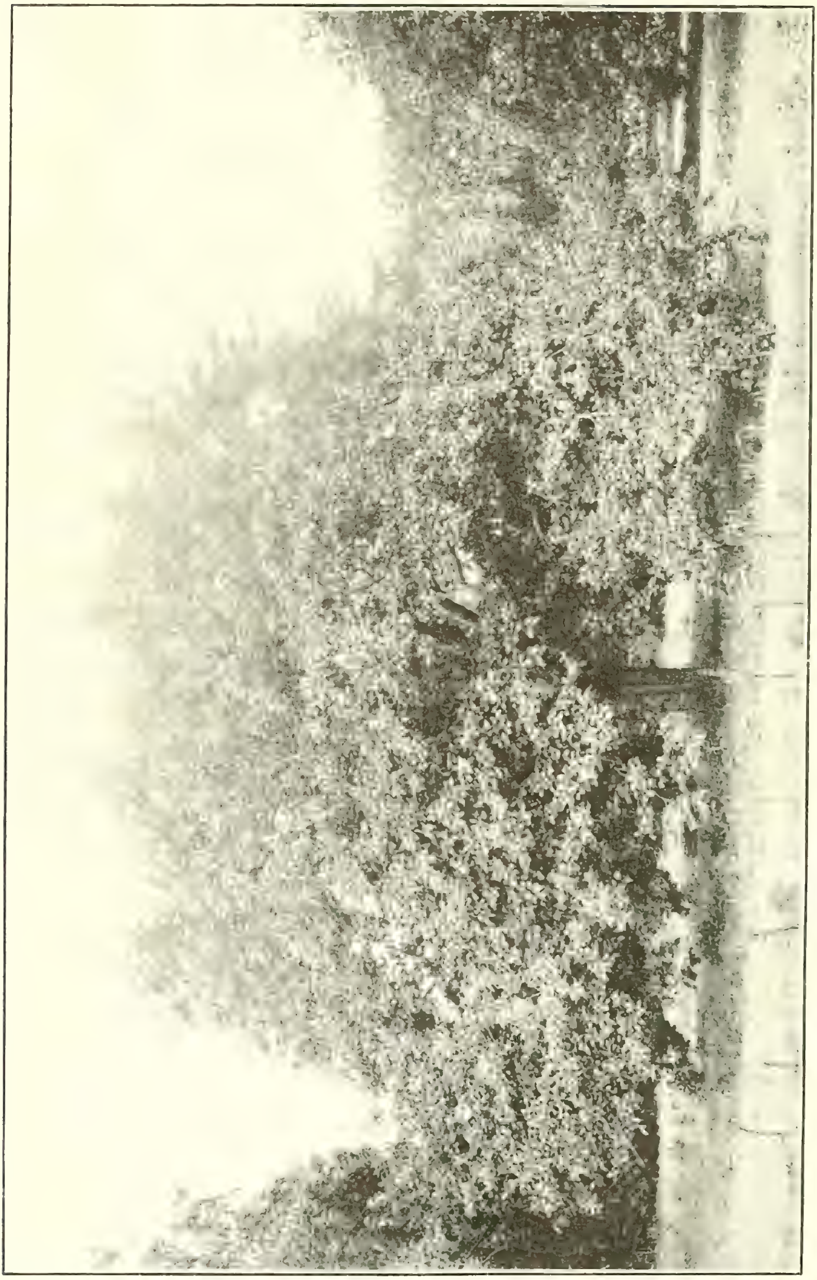
Soils so deficient in humus as to be leachy in case of sands, or stiff, intractable, and cloddy in the case of clays, clay loams, and loams should have their humus content increased until these unfavorable conditions for crop growth of any kind be overcome so far as possible. But there are marked limitations even to this fundamental kind of soil amendment, as it is not possible by the addition of plenty of humus so to change the physical and structural characteristics of a given soil that these inherent characters will become negligible so far as its adaptation to crops, or to different varieties of the same crop, is concerned. The agricultural practice of the eastern United States furnishes many examples of the special adaptation of particular soils to crop varieties.

In the Connecticut Valley of Massachusetts and Connecticut the physical character of the soil not only determines what specific crops shall be grown on the different types, but the adaptability of those soil types to such special crops has in turn been the principal basis of land valuation there for the last half century. The soils are all alluvial, and the variation in elevation is in no case more than a few feet. One of the sandy loams is the best type for the wrapper



ENORMOUS OLD BALDWIN ON GLOUCESTER LOAM AT IPSWICH, MASS.

[This tree is still yielding heavily.]



WELL-SHAPED OLD BALDWIN ON GLOUCESTER LOAM, GREENWICH, CONN.

[Notwithstanding its age this tree produces heavy yields.]

leaf tobacco; hence a normal price for many years has been $150 to $200 an acre, though it is now considerably higher than that. It is also a good onion soil, but brings no more profitable returns from that crop than a loam which, under identical cultural treatment, gives a cigar leaf so much thicker and poorer in quality that no one longer persists in trying to grow tobacco on it. Hence a relative price for this soil type is $100 an acre where one location is in every way equal to the other. It should be noted, too, that the best of the tobacco lands contain 1.5 to 2.75 per cent of organic matter. Hence the natural adaptation of that soil does not depend, it need hardly be said, on an unusual organic content; neither may other soils of that locality, though just as favorable for the growth of cigar leaf in every respect save that of texture and structure, be so amended by the addition of humus as to produce leaf satisfactory in quality.

Dr. Frear, in Bulletin No. 20 (above referred to), quotes Tscherbatscheff, a Russian tobacco specialist, who has studied with care tobacco culture in America, as follows:

> In Virginia and North Carolina the heavy or shipping tobacco is usually grown upon heavy loamy soils which for the most part have a red or dark brownish-red color and contain almost no humus. The tobacco of golden yellow color and pleasant aroma requires no thick layer of humus, so that for its culture * * * a sandy, or sandy loam, soil is selected.

The experience of growers is that this crop requires heat rather than moisture. In fact, in the presence of an excess of moisture it grows rapidly, the parenchyma thickens, and the leaf is larger, but at the expense of quality. Again, Mayor Ragland, of Virginia, is quoted as follows:

> A deep rich soil overlying a red or dark brown subsoil is best suited for the dark rich export type of tobacco. A gravelly or sandy soil with a red or light brown subsoil is the best adapted to the production of sweet fillers and stemming tobaccos. Alluvials and rich flats produce the best cigar stock. White Burley is most successfully grown on a dark rich limestone soil. For yellow wrappers, smokers, and cutters a gray sandy or slaty topsoil, with a yellowish porous subsoil, is preferable. The land must be loamy, dry, and warm, rather than close, clammy, and cold, and the finer and whiter the sand therein the surer the indication of its thorough adaptation to the yellow type. The soils so greatly affect the character and quality of the products that success is attainable only where the right selection of both soil and variety is made for each plant planted, and planters do well to heed this suggestion. Trial will determine what variety is best for any locality, as no one variety is best for all locations. To plant varieties unsuited to the type or on soil unadapted thereto is to invite failure every time.

In the rapid development of tobacco growing in Florida and near-by States during recent years soil selection has been one of the most important factors; indeed, within that very considerable district possessing a suitable climate soil selection has been of chiefest importance, and this phase of adaptation has been carried even to the point of breeding tobacco to suit local soil conditions.

The effect of soil influence on the quality and keeping characteristics of the particular variety of onion, Yellow Danvers, which has made the Connecticut Valley one of the leading centers in the United States in the production of this crop, also illustrates the principle of soil adaptation to specific variety. Grown on the sandy loam above referred to the bulbs are hard, fine-textured, and unexcelled in quality. When grown on the loam of the same series the texture of the onion is coarser, the necks do not cure down as well, and the bulbs are softer; because of these characteristics the latter are less desirable for storage purposes, and their culinary quality is inferior. The factor of edibility is not of sufficient importance to make any general difference in the selling price, but the hard onions are always sought by buyers for storage purposes, and on this account bring the top quotation when the market is dull, and sometimes even an advance price. When the crop moves slowly in the fall, moreover, the growers who store any part of their crop always select first for this purpose the hard onions. In actual practice this means those onions grown on the sandy loam soil. On heavier soils, with higher moisture content, the quality of the bulbs is correspondingly poorer.

In southwest Minnesota a shallow glacial valley some 3 miles wide divides the upland prairie which extends for many miles in a transverse direction. The irregular valley walls range in height from 15 to 30 feet or in some cases a little more. The valley soil is a clay loam, richly charged with humus. It is suited to grass and other forage crops, but wheat runs heavily to straw, none of the grain grading above No. 2, while much of it is No. 3. Wheat from the gray clay loam to the west of the valley, where the growth of straw and the filling of the heads is well balanced, gives a high percentage of No. 1 grain. Grown on the brown loam east of the valley, the grade is about half No. 1 and half No. 2. These lands have been farmed only 30 to 40 years, hence they have never been dressed to any appreciable extent with yard manure or commercial fertilizers. The superintendent of the elevator at the county seat where most of the grain is sold claims that he can tell on which of these three soil types a farmer, unknown to him, lives by the way his wheat grades. However this may be, the influence of the soil on the quality of the same varieties of grain is effectively shown by the money returns at the elevator.

In southeast Michigan the profit from sugar beets grown for the factory follows closely the character of the soil upon which the beets are grown. Beets from the light sandy soils have a high sugar content, with a high coefficient of purity, but the tonnage is relatively small. Moist, rich clay loams and loams yield a heavy tonnage, but the sugar content is low and the coefficient of purity very unsatisfactory. The farmers' goal is to secure the highest possible tonnage consistent with a high sugar content of satisfactory purity. This combination is best found there in a good strong sandy loam, underlain by a plastic light clay loam subsoil at a depth of 12 to 20 inches. Nearly as good is a deep, fine sandy loam extending to a depth of three feet or more.

Sea-Island cotton took its name from being grown on islands along the coast of South Carolina. Its long beautiful staple is now secured in northern Florida and other Gulf States when grown on deep, fine-textured loamy sands similar to those of the sea islands which it made famous. But on the heavy soils, or even shallow sandy loam surface soils underlain by heavy clay loam, it does not succeed and is replaced by the short-staple varieties.

In view of these definite cases in present agricultural practice, the different effects of varying amounts of soil moisture on soil temperatures and their apparent relationship to soil-crop adaptation is at least suggestive.

The greater the amount of moisture in a given soil and subsoil the lower is their temperature in summer. Hence, the more moisture, the larger the quantity of heat required to raise the temperature to any given degree. The removal of drainage waters is followed by rise in temperature at any given depth below the surface. Consequently capillary rise of moisture from this lower supply temporarily lowers the temperature of the layers of soil to which it ascends. The amount of capillary soil water held by the soil below the depth to which tillage has taken place does not in many cases depend primarily on the amount of humus in these lower layers of soil. A simple analysis of the case makes this point evident. When the forests were removed in the eastern States for crop planting the decaying roots left considerable amounts of humus to a depth of several feet. The depth varied greatly on different soils, because the different species of trees in the virgin forests showed very marked preferences for certain soil conditions. The local name "black walnut land" is still used where that hardy tree grows, to indicate a heavy type of soil. In southwest Michigan this is the Miami clay loam. The hickory thrives in the northeastern States on the heavier soils. Both black walnut and hickory are deep-rooted trees. In the same region "hemlock land" always indicates a sandy soil, and the hemlock is not a deep-rooted tree. In the orchard districts of West Virginia the leading peach growers will not tolerate "white-oak land," but a mixed growth of "rock oak and chestnut," about one-third of the former and two-thirds of the latter, indicate a soil which has been instrumental in making one of the most famous fruit districts in the world. The rock oak and chestnut growth indicates a soil somewhat stronger than that of chestnut alone, as a better supply of moisture is maintained; newly cleared, it is more productive, and even on old ground better results are secured from fertilization. The subsoil is finer textured, or more clayey, than the chestnut subsoils, but still is not so heavy as the white-oak soil. Yet on the latter some varieties of apples thrive.

Carrying the matter of soil adaptation to the different varieties of oak a step farther, it is a matter of common observation that poor and thin soils often support only the dwarfish blackjack oak and the post oak.

Shreve states in volume 3 of "The Plant Life of Maryland" that—

> While the general distribution of the loblolly pine is determined by historical and climatic factors, yet its relative abundance at different localities within its area is determined by the character of the soil. * * * It is most abundant on light sands and on the Elkton clay. While these soils may seem to be very dissimilar in their relation to the movement of soil water, yet the texture of the latter causes it to hold to its stores of water so tenaciously that plants growing in it often suffer drought when there is an abundance of water within very short distance but firmly held by the capillarity of the fine soil.

This statement indicates that this particular variety of pine flourishes on soils that furnish relatively small amounts of moisture to vegetation. In comparison, it may be commonly observed that the white pine flourishes best on heavy sandy loams and on very light mellow loams, soils on which the minimum supply of capillary moisture available to plants does not descend as low as with the loblolly pine soils.

Since the time when the forests of the eastern States were first cleared away for crops, the most common rotation has been corn, oats, wheat, and grass. Clover has very often been seeded with the grasses. Potatoes, buckwheat, and garden crops have also been of importance. All of these crops have shallow root systems except clover, and possibly corn which may be classed as medium in root penetration. Not enough of the deep-rooted clover has been grown on many farms to keep up the supply of subsoil humus, in conjunction with the humus supply of the surface soil—plant roots, stubble, and stable manure, which do not get below plow depth to any appreciable extent. This system of cropping with decreasing yields makes it apparent that the humus content of the subsoil on most farms has been for a long time at a minimum point. Were such a supply available to crops the average yield of corn would be much increased, and the greater amount of capillary subsoil moisture would in marked degree lessen drought injury to shallow rooted crops.

It becomes evident then, that the capacity of a subsoil to furnish capillary or usable moisture to crops depends, under average conditions, primarily on the natural character of the subsoil itself, *i. e.*, on the size of the soil grains, and that it is practically independent of the supply of humus. The supply of humus in the surface soil, on the other hand, greatly lessens the loss from evaporation and increases the moisture-holding capacity, both as referred to the rise of the capillary water and to light rainfall. Below the depth of a foot, moreover, surface heat penetrates very slowly. Hence, it is reasonable to suppose, in want of definite experimental data to prove the point, that the water-holding capacity of the subsoil, as determined chiefly by its texture, has an important bearing on the temperatures surrounding the roots of trees and plants. It is to be regretted that accurate experimental data are not available on this subject. The extensive series of observations upon soil temperatures at different depths, carried out in different parts of the United States and in foreign countries, have neglected to take account of the moisture content of the soil at various depths where the temperatures were measured. It is a well-observed fact, however, that in irrigated orchards any overirrigation prevents good color on either apples or peaches.

Dr. D. T. MacDougal, in his research work for the Carnegie Institution, of Washington (1908), concludes that—

The facts disclosed as to the actual temperatures in the soil, the diurnal and seasonable changes therein, lead to the belief that the differences in temperature of the aerial and underground portions of plants can not fail to be of very great importance in the physical and chemical processes upon which growth, cell division, nutrition, and propagation depend.

Desert soils have a low humus content, and, consequently, they offer excellent opportunity to observe the effects of variation in texture and structure of the mineral particles themselves. Eliminating soils influenced by alkali, Dr. MacDougal remarks:

On all other soils in which clay, loam, sand, or rocks predominate the feature which has the greatest determining influence (on adaptation to plants) is that of the amount and disposition of the moisture. Many striking dispositions of the root systems are being discovered which can only be correlated with the moisture factor.

E. S. Goff[1] adduces observations to show that the temperature of the water at the time it enters into the roots from the soil has some relation to the temperature of the stem of the plant for a short distance above the surface soil, and that the distance up the stem to which this temperature is felt depends upon the rapidity of the flow

[1] Agr. Sci., Vol. I, p. 134, Bul. 36, U. S. Weather Bureau.

of the sap and, therefore, ultimately on the rapidity of transpiration from the leaves. And again:

A warm summer is always accompanied by a high temperature of the ground or by a rise of its temperature. The increase is the more decided the more the excess in the temperature of the air is accompanied by a large quantity of rain or has been immediately preceded by it. In warm and comparatively dry summers the rise of the earth's temperature does not perceptibly exceed the normal. * * * The dampness of the soil is sufficient to allow the variations in the temperature of the air in winter and spring to exercise a decided influence upon those of the soil, whereas, in summer an excess of rain would be necessary to accomplish this, and that, too, to a greater degree if the soil be covered with vegetation.

Quetelet, as far back as 1849, in his "Climate of Belgium," expressed regret that he had been unable in his crop-climate studies to consider the influence of the temperature of the soil, although "it is absolutely necessary so to do in order to treat the phenomena of vegetation in a complete manner."

Mr. Knight[1] has observed that "varieties of the same species of fruit tree do not succeed equally in the same soil, or with the same manure," and further, that this applies to the peach, pear, and apple, "as defects of opposite kinds occur in the varieties of every species of fruit, those qualities of soil which are beneficial in some cases will be found injurious in others. In those districts where the apple and pear are cultivated for cider and perry, much of the success of the planter is found to depend on his skill or good fortune in adapting his fruit to his soil.[2]

McClatchie and Coit,[3] in discussing varieties, state that—

The same variety reacts very differently to the various stimuli produced by different environments. Hence, we arrive at the commonly held and correct idea that each climatological area has its own peculiar set of varieties which succeed best under its own climate and soil conditions.

Hence it follows that the supply of soil moisture available to plants and the temperature of the soil to depth equaling or exceeding that of the root zone of plants and trees, seem to account in part at least for the phenomena of the soil-varietal adaptations. These two factors constitute the soil climate and in subsoils they are governed indirectly but chiefly by the texture and structure as related to the moisture supply. In the surface soil these have been or may be modified to some extent by the addition of humus, but the latter influence is entirely insufficient to control the matter of inherent adaptation of soil types to crops, or to different varieties of the same crop.

It is evident, then, that many of our crops bear testimony, both from experimentation and from well-established agricultural practice, to

[1] Lindley's Theory of Horticulture. 1841. Chap. 20.
[2] Bul. 61, Arizona Agr. Expt. Sta.
[3] Trans. Royal Hort. Soc., I, 6.

the influence of the soil factor, not only upon general crop production but also to some extent distinctively upon the different varieties of the same crop.

THE ADAPTEDNESS OF SOILS TO DIFFERENT VARIETIES OF APPLES.

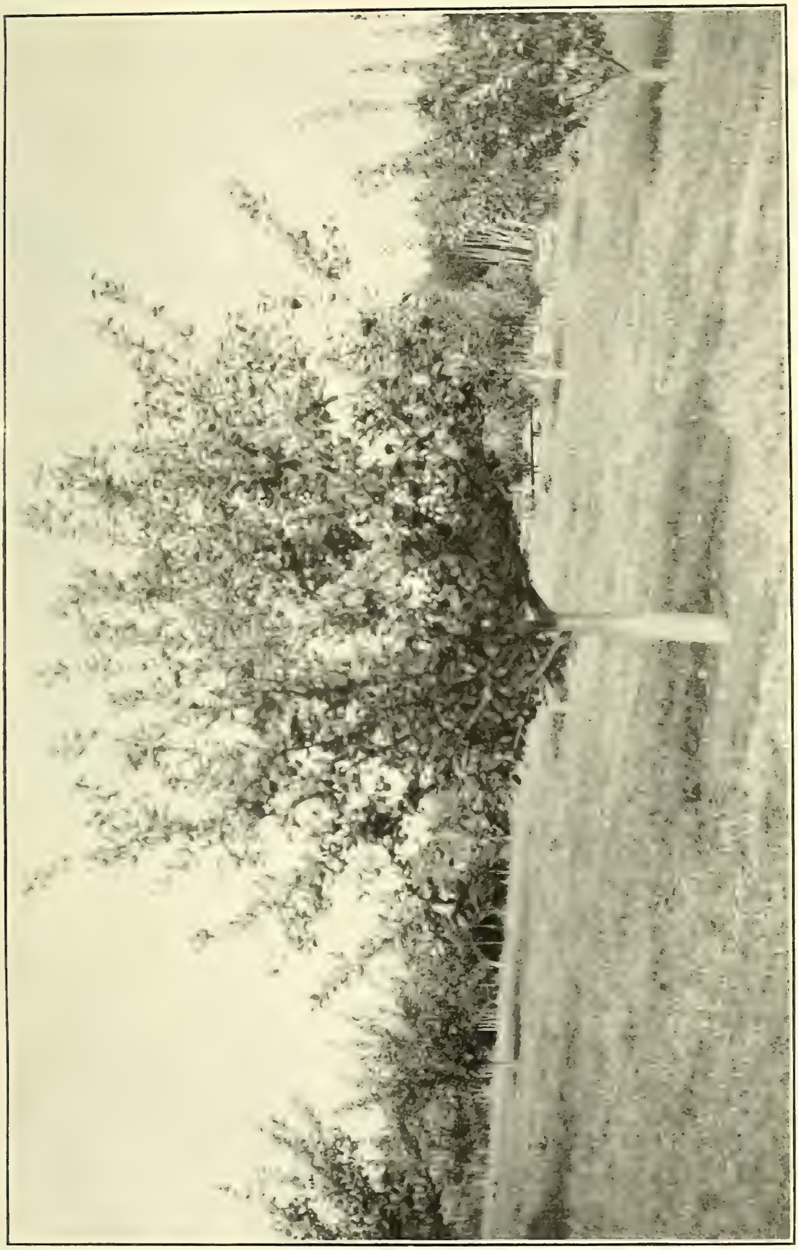
The character of the soil is only one of several factors that influence orcharding or other crop growth, and its importance in relation to the other agencies of climate, including temperatures, exposure, rainfall, surface drainage, etc., should not be overestimated. If, for example, the climatic conditions in any district are not favorable for a given variety, the character of the soil is of no importance to the practical grower unless it serves to offset in some degree the unfavorable tendency of the local climate. It is only within the climatic limits which favor a given variety that its behavior as influenced by the character of the soil may be studied. In like manner, surface drainage must be adequate, the water table far below the surface, and the exposures identical, or approximately so, before soil comparisons of value may be drawn. Apples ripen a bit later upon a northerly slope than on a southern one, the elevation, cultivation, fertilization, the soil, the age of trees, etc., being the same; but an earlier soil on the north side of the hill, such as a sandy loam, may mature fruit as early as a heavier soil on the south side, though most of these differences are comparatively slight.

The necessity for good depth of subsoil can not be emphasized too strongly. This applies to every variety of apple or other tree fruit and to every type of soil in every series. Shallow soils should be assiduously avoided for orchard purposes wherever they occur. The presence of unbroken rock, large ledges, or hardpan within 3 feet of the surface should be considered prohibitive. A soil depth of at least 6 feet should be insisted upon wherever possible and an even greater depth is highly desirable. Soils with the underlying rock too near the surface have been responsible not infrequently for the failure of commercial orchards in some sections of the country. This is due directly to the incapacity of the subsoil, on account of its limited depth and volume, to store sufficient moisture for the tree's needs when droughty conditions prevail or to get rid of excess moisture early enough in the spring or following extended summer rains. Subsoils devoid of stones are not infrequently found that are so clayey in texture or so stiff in structure as to produce results similar in kind even though usually less in degree.

If, on the other hand, soils and subsoils of the proper texture and structure have been selected, the presence of loose stones in the subsoil in distinction from underlying rock is immaterial so long as their quantity is insufficient to interfere to any great extent with the upward capillary movement of moisture. When soils have been chosen to advantage with a view to their adaptation to any given crop there is no virtue, it may be repeated, in the presence therein of stones, popular opinion as often expressed with regard to tree fruits notwithstanding. This fact may be no better demonstrated possibly than by some subsoils which are so clayey and stiff that they would have little value for tree fruits were it not for the presence of stones which in part offset their excessive compactness. Such a subsoil condition may make it feasible to plant an area that otherwise would be impracticable. But it is a difficult condition to determine; in most cases it is an unwise risk to run; and, furthermore, the soil and subsoil section should be of such character with regard to both texture and structure that no stones are needed to render them sufficiently pervious for the satisfactory movement of capillary moisture.

The common statement that stones conserve moisture in the soil, as is "proved" by its condensation on the underside of stones in its upward movement from the subsoil toward the surface, is very misleading. Granting that moisture is conserved to the extent of the area of the dimensions of the stones, the amount so controlled is not sufficient to render cultivation unnecessary for the conservation of more moisture, hence the dust mulch is still necessary to accomplish this end in cultivated orchards. In uncultivated orchards, where mulching is effectively practiced by hauling in relatively large quantities of material from outside the orchard, the presence of stones on or near the surface is usually of some assistance in conserving moisture, and this advantage is increased as the effectiveness of the artificial mulch (because too little in quantity) decreases. Stones are of most assistance in conserving moisture in neglected orchards where neither cultivation nor mulching is practiced, but even in this case the benefit is negligible.

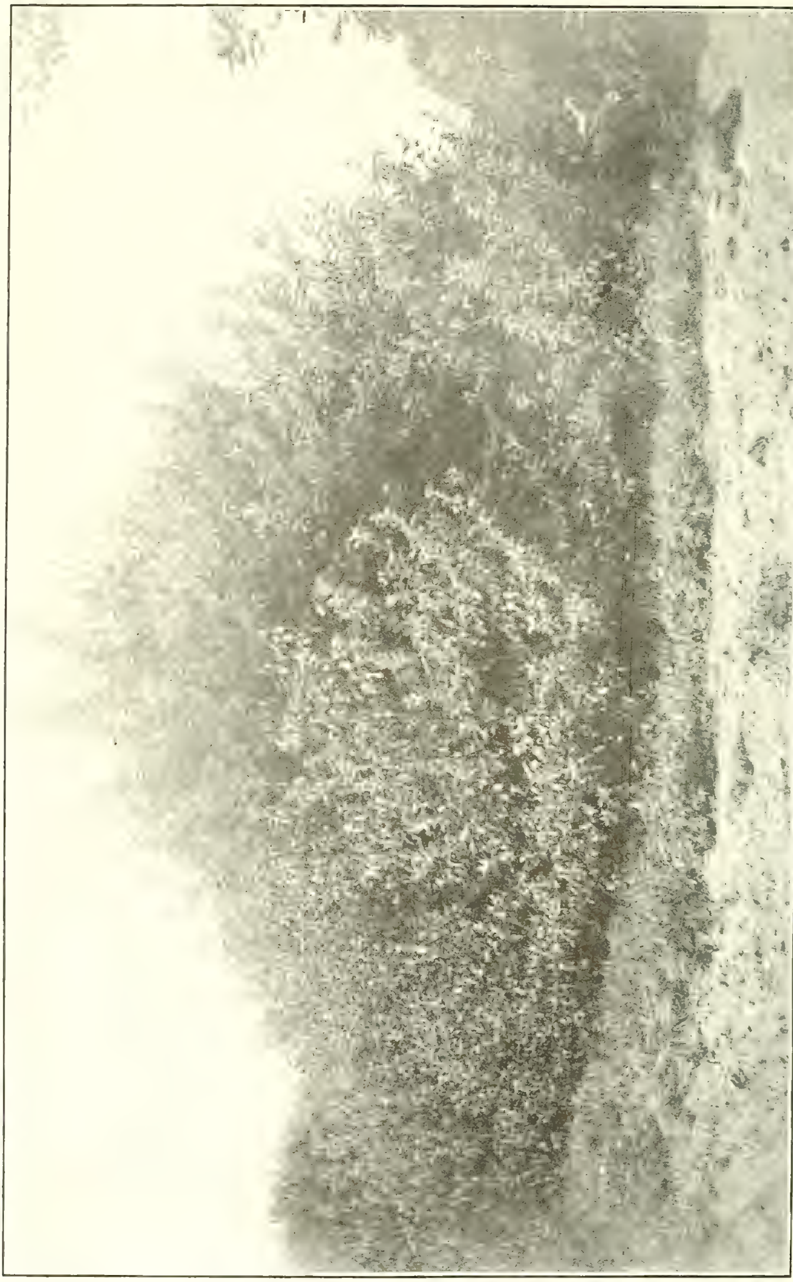
The term hardpan is in common use to designate a subsoil condition which delays the ready percolation of moisture. Its common use, however, has led to marked misunderstanding at least in the eastern States, as it unfortunately includes everything ranging from true hardpan to a clay loam which may constitute a desirable subsoil for orchard purposes. A true hardpan consists not of a subsoil containing sufficient clay to make it retentive of moisture, but of a mixture of sand, gravel, silt, and clay with more or less cementing material which so binds these ingredients together that the movement of soil moisture either downward or upward is seriously impeded; or a hardpan may consist of a thin layer of mineral matter formed by deposition of salts of iron, lime, or other minerals in solution after the formation of the soil or during the process. Such conditions within several feet of the surface are very undesirable. They sometimes occur in both Massachusetts and Connecticut,



SIX-YEAR-OLD BALDWIN ON GLOUCESTER STONY LOAM, CARRYING A GOOD CROP. FITCHBURG, MASS.

LOW-HEADED 14-YEAR-OLD BALDWIN ON GLOUCESTER LOAM, PRODUCING 7 BARRELS OF HIGH-GRADE APPLES IN 1912. SEYMOUR, CONN.

A SPRAY OF TREE IN PLATE X, SHOWING POSSIBILITIES OF FRUIT GROWING IN THE EAST.



RHODE ISLAND GREENING ON HEAVY PHASE OF GLOUCESTER LOAM—A FAVORABLE SOIL. GREENWICH, CONN.

though somewhat more extensively in the latter State. The percentage of such hardpan areas is not great. It is probable that they may be remedied by dynamite used in sufficient quantities to break up the hardpan effectively, this to be followed and supplemented by the use of deep-rooted leguminous cover crops to keep the shattered hardpan friable, but until the price of naturally good orchard land in the East is much higher than now it is unquestionably better economics to select soils which do not need the dynamite treatment to render them fit for planting fruit trees.

In a given block of orchard where a layer of hardpan is found at depths ranging from 15 to 30 inches, careful records for a number of years indicate that poor color with both Baldwin and Northern Spy is characteristic. In other cases, not alone in Connecticut, Yellow Bellflower is usually knotty when grown on hardpan soils.

In several orchards with surface soil of Gloucester loam but underlain in places with hardpan at depths of 18 to 24 inches and combined with a somewhat retentive subsoil, it is found impossible to grow Baldwin with good color if the orchard is cultivated. The character of the deep-soil section is such that the soil would be classed as somewhat moist, better for grass than for corn or potatoes, and so less conducive to good color of Baldwin than a soil less moist and warmer. This the owner wisely recognizes and so keeps his orchard in sod and removes the hay—a method usually condemned and properly so—but in this case well adapted to the conditions, for by transpiration of moisture through the grass plants the excess of soil moisture is reduced, thus making the soil warmer, and while the fruit is dark and dull colored at harvest time it reaches a beautiful color in midwinter, the flavor is well developed, the texture fine, and the keeping qualities remarkably good.

This case is mentioned in some detail because it illustrates so aptly the fact that cultural methods should always be flexible rather than absolute, and so fit the soil conditions of the individual orchard. If the soil is too retentive of moisture, evaporation should be hastened by noncultivation and also, if necessary, by transpiration through growing a crop. If the soil tends to dry out too quickly, cultivation should be frequent and a good supply of humus maintained to conserve the moisture. While such manipulation of method to suit the circumstances in the individual orchards should constantly be made use of, it has its limitations and does not do away at all with the desirability of selecting the soils best adapted to the individual variety; that is, those soils which will require a minimum of manipulation to effect the best soil environment. Such soil adaptation serves as a guidance, furthermore, to the moisture requirements of the different varieties, and so to the character of cultivation the different varieties should have.

Orchard fruits differ from annual crops in that they occupy the ground for a long term of years and are subjected to climatic conditions for 12 months in each year, and the transition periods from active to dormant in the fall, and especially from dormant to active in the spring are not infrequently a severe test upon the trees. It may be said, however, that the best results from orcharding are obtained only when all contributing influences are favorable. The soil, which is one of these, is the subject of this report, and a discussion of the other factors mentioned is not within its province except as their relationship to the soil is involved.

The condition of tree growth and fruit yields in large numbers of orchards makes it evident that soils for any kind of orchard planting should at least be deep, well drained and friable, yet not so porous as to be droughty. For the red varieties in New England both soil and subsoil should also be well oxidized as indicated by brown or yellow solid colors or possibly grayish-brown rather than by light-gray or mottled colors. The last especially should be avoided if possible. It may be added that it is not difficult to select upland soils in the States under discussion that are free from mottling, are well oxidized, deep, and located on well-rounded hills and gentle slopes where the processes of orchard practice are not unduly expensive. These soils are also of diverse mineral composition, and respond well in most cases where sufficient humus is supplied.

The ratio of leaf transpiration on pruned and unpruned trees to the moisture-holding tendency and moisture-furnishing capacity of the soil also adds greatly to the complexity of the problem of separating the influence of the soil factor upon varietal adaptation from the influence of other factors of environment known to bear upon varietal behavior. The physical limitations to be encountered in an endeavor to determine accurately this relationship postpones its solution to the indefinite future. So far as this investigation goes the endeavor has been to balance or to eliminate this factor of influence by the consideration of a large number of cases, but this, of course, only reduces the problem in the final analysis to one of individual judgment and leaves the actual problem for future investigation.

The discussion of the adaptedness of soils to varieties is based in part on the investigational work of the writer for several years past, as well as on the work of 1911 in Massachusetts, and 1912 in Connecticut. During the course of the field work it has been possible to observe the behavior of varieties under a wide range of soil and other conditions influencing apple production and meanwhile to gather much data from the experience of a great number of orchardists and farmers. Consistently has the attempt been made to check all such material by personal observation, likewise to study in a comparative way, as fully as circumstances would permit, the external appearance, the keeping character, the dessert and the culinary qualities of the fruit itself as affected by soil differences. The reader should keep ever in view the fact, however, that the soil is not the sole factor, but only one of several factors which together determine the adaptability of any given site to the different varieties of apples or of other tree fruits. It is perhaps needless to mention the difficulty of distinguishing the influence of the soil from various associated factors of climate, and it is fully realized that the data presented is not only very incomplete, but that much further study of the subject is needed.

CLASSIFICATION OF SOILS.

The classification of soils into groups by some arbitrary standard is not difficult, but it is no easy task for one unfamiliar with the process of such separations to make them fit the unmapped soils of a given farm. The many individual conceptions of a sandy loam may differ materially from the place in any definite classification scheme where it properly belongs. But this in no way lessens the necessity for a uniform plan for the grouping of soils, and in view of present knowledge the following plan has been adopted by the Bureau of Soils as the most logical.

The sands group[1] is classified as coarse, medium, fine, and very fine. The name implies that the subsoil as well as the surface soil consists of sand. A sand soil type usually contains as many as three of these grades and sometimes all four, but the predominating grade determines the type name—as a fine sand.

When enough of the finer particles, clay, silt, or both, are included with the sand to make the soil somewhat coherent and loamy, or, as often expressed, "to give it more body," the type is a sandy loam.

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[1] A key to the soil terms used appear in the following table:

Soils containing less than 20 per cent silt and clay:

Coarse sand	Over 25 per cent fine gravel and coarse sand and less than 50 per cent any other grade.
Sand	Over 25 per cent fine gravel, coarse and medium sand, and less than 50 per cent fine sand.
Fine sand	Over 50 per cent fine sand, or less than 25 per cent fine gravel, coarse and medium sand.
Very fine sand	Over 50 per cent very fine sand.

Soils containing 20 to 50 per cent silt and clay:

Sandy loam	Over 25 per cent fine gravel, coarse and medium sand.
Fine sandy loam	Over 50 per cent fine sand, or less than 25 per cent fine gravel, coarse and medium sand.
Sandy clay	Less than 20 per cent silt.

Soils containing over 50 per cent silt and clay:

Loam	Less than 20 per cent clay, less than 50 per cent silt.
Silt loam	Less than 20 per cent clay, over 50 per cent silt.
Clay loam	20 to 30 per cent clay, less than 50 per cent silt.
Silty clay loam	20 to 30 per cent clay, over 50 per cent silt.
Clay	Over 30 per cent clay.

If most of the sand is fine, rather than medium or coarse, the type is a fine sandy loam. When still more of the clay and silt are included, so that the proportions of sand and fine material are about equal, thus obscuring largely the grittiness of the sand, the soil is a loam.

When the clay and silt particles predominate only the fine grades of sand are usually present. If the silt grade is most abundant the soil is a silt loam. If clay is greatest in amount, the soil is a clay loam. And if the exceedingly fine clay particles constitute more than 30 per cent of the soil mass, the type is a clay, the other 70 per cent being primarily of silt and very fine sand. A soil containing as much as 50 per cent clay is very "heavy," while those containing 60 to 70 per cent, as along Lake Superior and Lake Champlain, are exceedingly stiff and hard to work.

The classification in the above table refers to surface soils. Where surface soils differ materially in color, as red and yellow, even though derived from similar geological materials, as the Wethersfield and the Middlefield soils, they are placed in different series. If two identical surface soils are underlain by subsoils, one of a sandy nature and the other clayey, they also are, or should be, placed in different series, as the light and heavy subsoils of the Gloucester series. If two soils and subsoils are identical in texture and color, but differ in the character of the geological material from which they are derived, as limestone and granite, they are placed in different series, to wit, the Dover and the Gloucester series. These distinctions all lie within a given soil province such as New England, or the Atlantic Coastal Plain, the Appalachian Mountains and valleys, etc., but on account of differences in climatic and consequent cropping characteristics the same series name is not used in two soil provinces, even though the soils are similar in color and derivation. This is illustrated in the Southern States by the Cecil and the Porters soils, the former occurring in the Piedmont Plateau and the latter in the Appalachian Mountains division.

In the Gloucester series loams and fine sandy loams are the predominating soil types in Massachusetts and Connecticut. Fine sand is next in importance, and on Cape Cod it is the most prevalent type. True clays and heavy clay loams do not occur. Even light clay loams are uncommon, heavy loams and silty loams constituting the heavy soils of the region. In the Wethersfield and Middlefield series the silt loams and the fine sandy loams are the most important types, though there is considerable loam and a little sandy clay.

SOILS FAVORABLE FOR THE BALDWIN.

If soils are thought of as grading from heavy to light, corresponding to the range from clay to sand, then soils grading from medium to semilight apparently fulfill best the requirements of the Baldwin, particularly under a system involving such average cultivation as is usually practiced in commercial plantings. Following definitely the classification standards of the Bureau of Soils with reference to the proportions of clay, silt, and sands, this grouping would include the medium to light loams, the heavy sandy loams, and also the medium sandy loams provided they were underlain by soil material not lighter than a medium loam nor heavier than a light or medium clay loam of friable structure.

From this broad generalization it will be seen that the surface soil should contain an appreciable amount of sand. The sands, moreover, should not be of one grade—that is, a high percentage of coarse sand would give a poor soil, whereas a moderate admixture of it with the finer grades of sand, together with sufficient clay and silt, would work no harm. In general, the sand content should be of the finer grades, but soils also occur, though comparatively rare, which would be too heavy for this variety were it not for a marked content of the coarse sands, the effect of which is to make the soil mass much more friable and open than would be expected with the presence of so much clay. Such conditions occur in parts of Perry County, Pa. Soil types having characters as above described dry quickly after a rain, and are not to be classed as moist soils. They will never clod if worked under moisture conditions that are at all favorable. The subsoil on the other hand must never be heavy enough to impede ready drainage of excess moisture, and it should be sufficiently clayey to retain a good moisture supply—that is, plastic, not stiff. If the subsoil be so clayey or heavy that moisture does not percolate down through it readily, or if the same result is caused by hardpan, a Baldwin of poor color with a skin more or less greasy is the usual result. The best results are secured, other circumstances being equal, from warm and "kind" yet not too sandy soils. Such soils can be so managed as to secure a sufficient but not excessive vegetative growth, the proper balance between it and the growth of fruit being readily maintained, a condition necessary to produce the best developed and highly colored fruit.

On heavy loams where Baldwin matures slowly, and is dark and dull at harvest time, the fruit sometimes possesses unusually good keeping qualities, and in some cases the color develops satisfactorily by midwinter. For storage such fruit is excellent.

Another unfavorable soil condition was noted in several instances in both Connecticut and Massachusetts. It is well illustrated in an orchard where the cause of the unsatisfactory color of fruit is due doubtless to the condition of the surface soil rather than to the subsoil which is a well-drained yellow to light-brown friable loam or light clay loam. The surface soil is dark-brown to grayish-brown heavy loam more retentive of moisture than the subsoil. Such a soil is better for Gravenstein or Fall Pippin.

The Bernardston soils are not quite so good as the Gloucester for the Baldwin and similar red varieties of apples because the fruit matures later and, under the climatic conditions which obtain where these soils are found, tends to a deficiency in color. On the basis of comparisons with similar soils in Connecticut this deficiency seems to be even more marked with peaches. The Rhode Island Greening is well grown, however, on these soils.

The apparent ideal to be sought is a heavy, fine sandy loam, or light mellow loam, underlain by a deep subsoil of plastic light clay loam or heavy silty loam. It is fully realized that many will not possess this ideal, but the soil that most closely resembles it should be chosen. If corn be grown on such soil the lower leaves will cure down in an average season before cutting time, giving evidence of moderately early maturity. This is one of the safe criteria by which to be guided in choosing soil for this variety in the New England section. Typical Gloucester loam conforms ideally to the above conditions and characteristic growth of the Baldwin on this soil at both low and high altitudes—50 to 1,000 feet—is shown in Plate X to XIV, inclusive.

Mention was not made in the above description of the color of the soil. The desirability of a surface soil of dark brown, the color being due to the presence of decaying organic matter, is unquestionable and generally recognized, and if the soil be not that color the successful orchardist will so make it by the incorporation of organic matter through the growth of leguminous crops or otherwise. It is often cheaper to buy soil with a good organic content or humus supply than it is to be compelled to put it there after purchase. Hence, this is purely an economic feature. The warning should be stated, however, that a soil should not be purchased or planted to apples of any variety because it is dark colored and rich in humus. Both soil and subsoil should be selected because of their textural and structural adaptation regardless of the organic content. Then if such soils happen to be well supplied with vegetable matter so much the better; if not, it may be supplied.

To modify, by the addition of humus, the physical condition of a sand until it resembles a sandy loam as far down as tree roots ordinarily extend, is unquestionably an expensive process, and as orchards are grown for profit the soils on which they are to be planted should be so selected for the different varieties as to furnish the most favorable conditions possible before going to the additional expense of trying to change their character artificially.

While soils so deficient in humus as to be leachy in the case of sands, and stiff, intractable, and cloddy in the case of clays, clay loams, and loams, should have their humus content increased until these unfavorable conditions for crop growth of any kind be overcome as far as practicable, it is impossible to ignore the effects of the inherent physical character of the soil itself as related to adaptation to crops, and, in some cases at least, varieties of the same crop. It is easily possible, furthermore, on soils of medium texture, especially, so to accentuate the vegetative habit of the Baldwin that the color of the fruit becomes impaired. In current orchard practice this is a common occurrence which growers seek to overcome by withholding ammonia-carrying fertilizers, by checking tillage, and by avoiding humus-forming cover crops. It lowers cost of production to let nature help as much as possible.

In both States nearness to salt water is sometimes suggested as a cause for deficient color of red apples, especially the Baldwin; and while sufficient evidence is not at hand to refute the statement completely, it is apparent in many cases that the difficulty is chiefly one of impervious subsoil. Low elevation is also a factor in some instances. In the Connecticut Valley, for example, 35 miles from the Sound shore, Baldwins do not color satisfactorily, even though the soil is favorable. At the highest altitudes in northern Berkshire and Franklin Counties, Mass., and farther north in Vermont, Baldwin shows a tendency to become slightly constricted and ridgy at the calyx end. It was not as plump in the season of 1912, at least, as at altitudes of 1,000 feet. The minimum elevation where this effect was noticeable in 1912 was around 1,200 feet, while at 1,600 feet, along the Vermont line, the tendency was more pronounced. It may be added, too, that the variety becomes more susceptible to winter injury at about this same point, thus suggesting proximity to those climatic conditions where Baldwin should be replaced by the Fameuse and McIntosh or others of the Fameuse group. As one drives in this locality from characteristic Baldwin territory through the transition zone to higher altitudes, where this variety no longer develops to its best, it is most interesting to note corresponding changes in the natural forest growth, and in the varieties of farm crops. With increasing elevation these changes are first noticed on exposed and wind-swept areas, where apple trees lean away from the direction of the prevailing winds. A given variety of flint corn becomes more dwarfed than at lower elevations. The hemlock, which prevails at 1,000 feet, gives way to spruce in protected situations, while the high ground, which is more exposed, is occupied with a much larger percentage of the hardwoods—beech, maple, black, and yellow birch.

While the hills of Massachusetts and Connecticut include a great deal of ideal Baldwin soil, or soil that resembles the ideal closely enough for practical purposes, they also include a great deal of soil that is not so well adapted to the Baldwin. The greatly superior color of the fruit from some orchards on mellow, friable loams, when compared with that from others on a more retentive kind of soil and subsoil—certain clay loams of the same series or moist loams of a different series—elevation, slope, methods of culture, and fertilization being virtually the same, gives striking evidence of the importance of the soil factor. On just this basis the fruit from some orchards sells for a higher price than that from others. This illustrates the economic advisability of selecting the orchard site with soils adapted to the variety to be planted.

SOILS FAVORABLE FOR THE RHODE ISLAND GREENING.

As the best prices for the Rhode Island Greening are usually obtained in New York City the majority of commercial growers have aimed to meet the preference of that market. The demand there for a "green" Greening has usually been stronger than for one carrying a high blush; and while individual buyers may be found, it is said, who do not discriminate against the latter, many of them do. Not infrequently the "green" Greening brings a premium of 25 cents or more a barrel over the "blush" Greening. Of even more importance sometimes is the fact that a "green" Greening will move on a slow market when a "blush" Greening fails to do so. There is also a trade objection to the "blush" Greening from the fact that the consumer is rarely able to distinguish it from Monmouth, a red-cheeked green apple, which does not serve at all well the purpose for which the Greening is usually bought. In view of these trade conditions the writer has especially sought those soil characteristics which best contribute to the production of a "green" Greening, and in previous writings or in meetings addressed, the soil adaptations for the Rhode Island Greening have been described with the green type of apple as the standard sought. Bearing this ideal in mind, the soils adapted to this variety are distinct from the Baldwin standard. A surface soil of heavy silty loam or light silty clay loam underlain by silty clay loam excels for the "green" Rhode Island Greening. Such soil will retain sufficient moisture to be classed as a moist soil, yet it is not so heavy as ever to be ill-drained if surface drainage is adequate. The soil should be moderately rich in organic matter, decidedly more so than for the Baldwin. In contrast to the Baldwin soil in the growth of corn, it should keep the lower leaves of the plant green until harvesting time, or at least until late in the season. Such soil conditions maintain a long seasonal

EXCELLENT 6-YEAR RHODE ISLAND GREENING INTERPLANTED WITH PEACH ON VIRGIN WETHERSFIELD LOAM AT WALLINGFORD, CONN.

[Greening tends to blush a little earlier than on the Gloucester loam. Compare Pl. XV.]

NORTHERN SPY ON WETHERSFIELD LIGHT SILTY LOAM AT GOOD LOCAL ELEVATION IN CONNECTICUT VALLEY, MASS.

[Few of this variety are being planted, although individual trees show excellent results.]

growth under uniform conditions of moisture and thus produce the firm yet crisp texture and the remarkable juiciness for which this variety is noted.

A dealer in cider apples who has bought the fruit from two orchards on the same farm in northeastern Massachusetts for many years testifies that the apples from the orchard with subsoil of heavy loam to clay loam yield from 5 to 7 per cent more juice than apples from the orchard on sandy soil and subsoil. On the State farm at Bridgewater, Rhode Island Greening is very successfully grown on a rich, heavy loam from 10 to 16 inches deep. The fruit is large and is said to keep well until January in common storage. On the sandy soils in the same region it is usually described as a fall apple. If a high blush is desired, however, to meet other market requirement, a soil somewhat warmer than that described should be selected—a deep, light, mellow loam or productive fine sandy loam being favorable. To secure a "finish" of this character, soils approaching more nearly to the Baldwin standard are best adapted.

Plate XV shows Rhode Island Greening on heavy Gloucester loam. Fruit is large and green. Plate XVI shows a tree yielding heavily at six years of age on Wethersfield loam—a soil somewhat lighter than the Gloucester loam in the preceding plate.

In northwestern Massachusetts on the heavy phase of Gloucester loam Rhode Island Greening bears heavily. The fruit is firm in texture, of excellent quality, and keeps well until late winter. The blush is usually well developed. The variety is highly profitable in this locality, but the call for red apples among the buyers who come there is so strong that no Rhode Island Greenings are included in the younger plantings.

The loam and silt loam of the Bernardston series of the Western Highlands are also especially well adapted to the Rhode Island Greening, giving greener fruit than the Gloucester loam.

In eastern Massachusetts the variety drops from the trees earlier than in the western part, but this is undoubtedly due largely to the difference in elevation. This tendency would doubtless be retarded somewhat by planting on heavier soils.

In southern Connecticut and somewhat farther north in the Connecticut Valley, Rhode Island Greening is generally found less satisfactory than in Massachusetts. In many cases the fruit is not a deep, dark green even at harvest time, but rather a pale green, with sometimes a suggestion of yellow. As the fruit ripens it rapidly becomes more yellow and the apple is much less desirable than that grown in western Massachusetts or at good altitudes in Litchfield County, Conn. The flavor is not well developed, the texture is not as fine, and the keeping quality is poorer, most of the fruit being consumed before New Years. In fact, the variety as grown in southern Connecticut, even on soils adapted to it, is not as well developed as that from the northern half of the Connecticut Valley in Massachusetts, notwithstanding the low elevation there. Even in Litchfield County, in orchards well cared for, Rhode Island Greening has not in some cases given yields sufficiently large to make it as profitable as Baldwin. These various limitations indicate that Rhode Island Greening is more restricted in its range of adaptation than the Baldwin, and that it does not adapt itself to climatic conditions as far south as the Baldwin, even though suitable soils occur there. In fact, its southern boundary may be roughly estimated at 0.25° north of the forty-first parallel. South of that it becomes a fall apple and keeps very poorly.

SOILS FAVORABLE FOR THE HUBBARDSTON.

Compared with the Baldwin soil requirements, the heaviest soils desirable for the Hubbardston lap over for a little upon the lightest soils desirable for the Baldwin, while at the other extreme the Hubbardston will utilize to advantage a more sandy soil than most other varieties of New England. This does not mean that it will succeed on poor light sands, for on such soils the apple will not attain sufficient size to be of value, nor is the tree vigorous enough; but the soil should always be very mellow. A rich, fine sandy loam to a depth of at least a foot is preferable, and the subsoil well may be of the same texture. The Hubbardston does remarkably well on a rich fine sandy loam in the Connecticut Valley in Massachusetts where fertilized highly enough for tobacco, onions, or garden crops. The fruit is of good size, well colored, and with good keeping qualities. Baldwin grown alongside is poorly colored and inferior in both flavor and keeping quality, yet on the same soil where the humus content is lower, and the soil less rich, the fruit is much better in all these respects. This warrants the conclusion that on this soil humus and nitrogen-carrying fertilizers may easily be supplied in too great amounts for the Baldwin, and that Hubbardston can use more of them to advantage than Baldwin. This indicates relative soil conditions for these varieties, and, to some extent, fundamental soil selection also. A subsoil containing enough clay to make the fine sandy material somewhat coherent, or sticky, is not objectionable for Hubbardston, but there should never be enough clay present to render the subsoil heavy. If the soil is too heavy or too clayey the fruit is liable to have a greasy skin and a deficient color, the fruit tends to be small and the flavor is insufficiently developed. This last tendency was very noticeable in 1912 in an orchard which receives good treatment but is underlain with hardpan at depths ranging from 18 to 24 inches. In 1912 the color was good, but the owner stated it also to be deficient in normal seasons. The light phase of the Gloucester loam gives much better results with Hubbardston than the heavier subsoil phase but this variety is not commercially popular in the eastern half of Massachusetts where so much of the lighter phase occurs. Neither does it do well on the Gloucester soils of Northwest Massachusetts where the elevation is 1,000 feet or more.

In one Essex County orchard, Hubbardston is excellent as grown on a surface soil ranging from heavy fine sandy loam to light loam with subsoil of fine sandy loam (Gloucester fine sandy loam). There is good local elevation, though the orchard is slightly less than 100 feet above sea level. The productivity of the land has been well maintained, so in this respect it may be compared with the Connecticut Valley soils mentioned. Stable manure has been the principal fertilizer, and the orchard is fenced and used as a poultry yard. The number of hens is not sufficient to prevent some growth of grass. Until a few years ago, wood ashes were applied in small amounts. The trees show a thrifty growth, and the fruit keeps well. The color of the fruit is said to be superior to that from trees on a heavier soil in another part of the same orchard.

In most places in Connecticut, and especially in the southern part, the Hubbardston is not held in high esteem, and it seems not as well grown as farther north in Massachusetts.

Sutton (Beauty) is adapted, so far as we have been able to observe, to about the same range of soils as the Hubbardston. In the town of Sutton where it originated, and in the surrounding section, it seems especially promising on the Gloucester fine sandy loam. Sufficient plantings have not been found, however, for adequate comparison on a commercial scale.

SOILS FAVORABLE FOR THE NORTHERN SPY.

This variety is one of the most exacting in soil requirements. To obtain good quality of fruit—i. e., fine texture, juiciness, and high flavor—the soil must be moderately heavy, and for the first two qualities alone the "green" Rhode Island Greening soil would be admirable. The fact that the Northern Spy is a red apple, however, makes it imperative that the color be well developed, and the skin free from the greasy tendency. This necessitates a fine adjustment of soil conditions, for the heaviest of the soils adapted to the Rhode Island Greening produce a Northern Spy with greasy skin and usually of inferior color. The habit of tree growth of this variety, moreover, is such as to require careful attention. Its tendency to grow upright seems to be accentuated by too clayey soils, if well enriched, and such soils tend to promote growth faster than the tree is able to mature well. On the other hand, the Spy from sandy soils, while possessing good color and a clear skin, is often unsatisfactory in texture and flavor, especially if the fruit be held for very long in open storage. The commercial keeping quality, too, is said to be inferior to that of the Spy grown on heavier soils in the same district. Hence the soil requirements of this variety are decidedly exacting, and are best supplied apparently by a medium loam underlain by a heavy loam or light clay loam; that is, a soil as heavy as can be selected without incurring the danger of inferior drainage, for a poorly-drained soil should in no case be used. It is surely best not to plant Northern Spy on a soil lighter than a very heavy fine sandy loam, underlain by a light clay loam, or possibly a heavy loam. Good elevation and good air drainage are also very essential with this variety.

In the southeastern counties of Massachusetts, Northern Spy has not been very satisfactory, but rarely has it received suitable care. In southern Connecticut, even when grown on soils very well suited to it, the Northern Spy is held in much less esteem than in the northwestern part of the State, where the conditions much more nearly resemble those in western Massachusetts, a district in which the variety is excellent when grown on the right kind of soil with sufficient altitude. In the northeastern part of Hartford County, at elevations approximating 300 feet, Northern Spy does not keep well much after New Years. Plate XVII shows excellent growth of this variety under favorable conditions.

SOILS FAVORABLE FOR THE WAGENER.

In northeastern Pennsylvania, where the climatic conditions are not greatly dissimilar to those of southern New England, Wagener is one of the most profitable sorts for filler purposes. It gave remarkable results, too, in northeastern Massachusetts in 1911 at a very low altitude, and in the western part of the State, at an altitude of nearly 1,200 feet, it is also doing very well, indeed. The tree is weak in growth, hence a soil that is deep, strong, mellow, and loamy should be selected. Stiff subsoils are especially objectionable with this variety, and thin soils and light sandy soils should be avoided. The Wagener thus fits in nicely with Northern Spy in soil requirements, and its habit of early bearing makes an effective offset to the tardiness of the Northern Spy in this respect.

SOILS FAVORABLE FOR THE M'INTOSH.

The McIntosh is an apple of high quality that is now very popular. As McIntosh trees of sufficient age for safe comparisons are rarely available in Massachusetts or Connecticut over any considerable range of soil conditions, no positive statement is made concerning the soil preferences of this variety. The indications are, however, that the heavier of the Baldwin soils as described are desirable for the McIntosh. (See Pl. XVIII.) From the experience in Connecticut so far available this variety seems to yield somewhat heavier crops at the highest altitudes in the northern part of the State than in the southern part; there is less trouble from dropping and the fruit has better keeping quality. Even in the northern counties at elevations as low as 300 feet there is much loss from dropping, the tree does not yield satisfactorily, and the fruit is not as crisp as at higher altitudes.

SOILS FAVORABLE FOR THE TOMPKINS KING.

The Tompkins King is fully as exacting as Northern Spy in soil adaptation. The tree, with its straggling tendency of growth, does not develop satisfactorily on sandy soils, but succeeds best on a moist yet well-drained soil, i. e., the light Rhode Island Greening soil, a soil capable of maintaining such supply of moisture that the tree receives no check at the approach of drought. But the fruit grown on soils so heavy often lacks clearness of skin, and the appearance of the apple is marred by the greenish look extending far up the sides from the blossom end, and the lack of the well-developed color which makes this fruit at its best very attractive. A layer of hardpan within a few feet of the surface may produce similar effects. Hence the problem is to balance these two opposite tendencies as well as possible, and soil of the following description seems best to do this: Light, mellow loam, the sand content thereof being medium rather than fine, thus constituting an open textured loam rather than a fine loam. A subsoil of the same texture or only slightly heavier is favorable, and one heavier than a very light, plastic clay loam or inclining toward stiffness in structure should be avoided. For this variety the productivity of the soil should be at least moderately well maintained.

SOILS FAVORABLE FOR THE FALL PIPPIN.

Soils adapted to the Fall Pippin are somewhat wider in range than those described for Northern Spy and Tompkins King. In fact, this variety may be very successfully grown on the soils described for both the Tompkins King and the Northern Spy. It is preferable, however, that the surface soil be a fine loam rather than the open-textured loam described for the Tompkins King.

Another soil combination which has given very good results in Connecticut is a strong loam 10 to 12 inches deep, underlain by sandy loam which offsets in a measure the retentiveness of the surface soil.

SOILS FAVORABLE FOR THE ROME BEAUTY.

The commercial worth of Rome Beauty for New England is yet to be determined. In middle latitudes it bears the same relation to the Grimes in soil requirements that Baldwin does to the Rhode

Island Greening in their respective regions. There is, however, something of an overlapping of regions. That is, the Baldwin extends farther south in adaptation than the Rhode Island Greening, and the Rome Beauty extends as far north as the Grimes. But this intraregional overlapping of Rome Beauty and Baldwin is largely a matter of dovetailing due to variations in elevation. Thus in southern Pennsylvania, as the Baldwin in its southern extension seeks its soil at higher elevations to offset the climatic changes, so does Rome Beauty in its northern extension seek the same soil at a lower elevation for the same reason.

With increasing distance south, the Baldwin very soon becomes a fall variety, and where this tendency is sufficiently pronounced to lessen materially its desirability it may well be replaced by the Rome Beauty, which is adapted to the same kind of soil.

Rome Beauty is grown with fairly good success in the lower Hudson Valley and at low elevations in western New York, but there is question if it will become a leading commercial sort in either region.

SOILS FAVORABLE FOR THE BEN DAVIS AND GANO.

The reference to the Ben Davis and Gano here should not be construed as a recommendation for planting in this region, for it is believed they should not be planted in Massachusetts or in Connecticut, but they are mentioned simply because of the value they may have in this discussion of fruit soils. These varieties are adapted primarily to the middle latitudes of this country rather than to the northern ones, and it is believed that the latter can not, for this reason, compete successfully in their production. The influence of the soil factor on these varieties is somewhat less marked than with varieties of higher quality, though the best color is not developed on soils excessively clayey or ill-drained. The Ben Davis has a tendency to bear annually better than most other varieties, but there are other sorts of good quality that are sufficiently productive to make the planting of the Ben Davis and Gano ill-advised for this section of the country.

SOILS FAVORABLE FOR THE GRAVENSTEIN.

The Gravenstein has given growers in Massachusetts much trouble, but its general excellence, the high price the fruit brings, and the strong demand for it in some markets makes the Gravenstein a tempting sort to plant. Its susceptibility to winter injury, however, is often a serious matter. There is good evidence to show that Gravenstein should not be forced in growth, at least until it is 15 years old or older. In western Middlesex County, on rich moist ground or with heavy fertilization with nitrogenous manures, its growth is rarely matured early enough in the season to avoid more or less winter injury. It often continues to grow until freezing weather and thus is very susceptible to injury. On a medium soil, neither too moist nor too rich, its growth may well be held in control, early annual maturity may be forced, and the color of the fruit from such soils is satisfactory. (See Pl. XIX.) The subsoil should never be so clayey as to prevent ready downward percolation of any excess of free soil water. Annual applications of the mineral fertilizers, such as basic slag and potash, seem desirable on such soils, and a moderate amount of humus should be furnished, but nitrogenous fertilizers should be used sparingly. If the growth is too vigorous at any time it is well to seed to grass at once.

Fruit of good color is especially desirable with this variety, the color adding materially to the selling price. This has led to its being planted on thin or light sandy soils in some cases, but on such land the Gravenstein is generally unsatisfactory.

In Massachusetts and Connecticut the Gravenstein is a variety for the specialist only, but for such it is very profitable when grown near a market, especially if within driving distance. Gravenstein is a good illustration of a variety that is difficult to grow well but which brings high profits if it reaches market in good condition. This has doubtless led to its planting under conditions that have not always been favorable. Market demands may make it profitable and desirable to grow a variety even though soil conditions are not ideal and the variety does not grow its best.

To secure the best color the fruit must be left on the tree in most seasons until the loss from dropping becomes serious. By mulching heavily with poor hay or straw these drops, many of which will be well colored, may be gathered clean and practically free from bruise. They will not keep long, but at that season the market is usually eager for them at good prices. Most of the Gravensteins in Massachusetts are grown within driving distance of some of the larger markets, especially between the radii of 10 and 25 miles from Boston, where the drops sell to good advantage and the variety is considered highly profitable. Many of the smaller cities in Massachusetts are not well supplied with this variety, however, and in some cases there is good opportunity for the specialist to plant Gravenstein for local markets, as the large markets always take any surplus of the best grade at high prices when well packed.

SOILS FAVORABLE FOR THE ROXBURY (ROXBURY RUSSET).

The Roxbury is now seldom planted, but there are some commercial orchards of it in Massachusetts, and many of the old orchards contain a few trees. It is most extensively grown in the Oldtown district of Newbury, near Newburyport. The Roxbury is a gross feeder, the growers believing that it will use to advantage heavy applications of stable manure.

In one of the most successful orchards the surface soil consists of a heavy loam from 10 to 15 inches deep, which has been highly fertilized with stable manure and kept well supplied with humus for at least 50 years, the very antithesis of the soil conditions desired for the Baldwin (see Plates IV and XX). The subsoil is lighter, a fine sandy loam or a gravelly sandy loam. The soil of another excellent orchard consists of a light silty and fine sandy loam underlain by fine sandy loam.

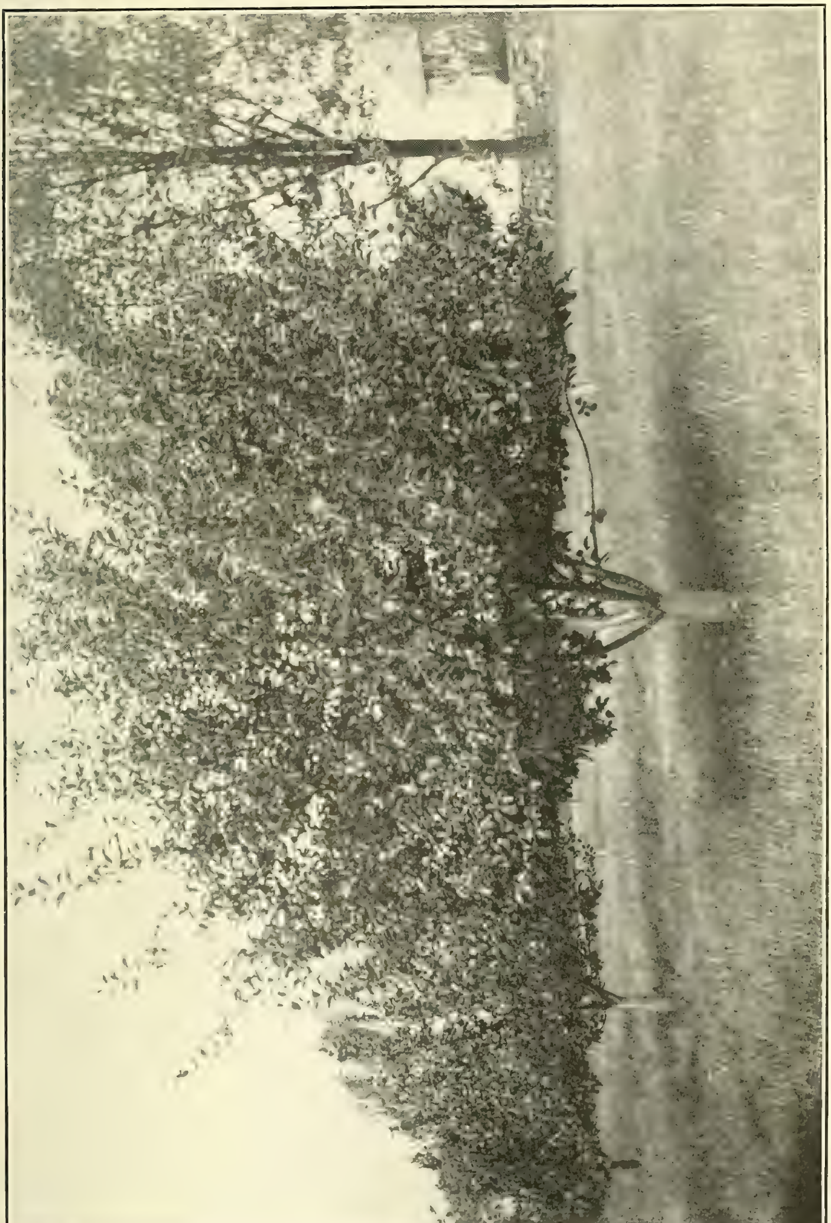
A deep, rich, loamy soil with the upper subsoil of at least medium porosity seems to be essential, though a heavier subsoil at a depth of 4 to 6 feet is apparently not objectionable. The first orchard mentioned is underlain by a retentive subsoil of clay loam to clay, at a depth of about 6 feet. The Roxbury thrives on a much richer soil than the Baldwin, which does not color well on the best russet soils. The "green" Rhode Island greening soil, on the other hand, is somewhat too clayey for the Roxbury.

Grown on the soil conditions described, the Roxbury tree is prolific in Massachusetts, the fruit attains large size and good quality, its keeping characteristics are excellent, and it brings a good price, especially for export trade. Young trees of this sort are now so rarely planted that there would seem to be a good opportunity for it in a limited way to supply the small yet definite demand.

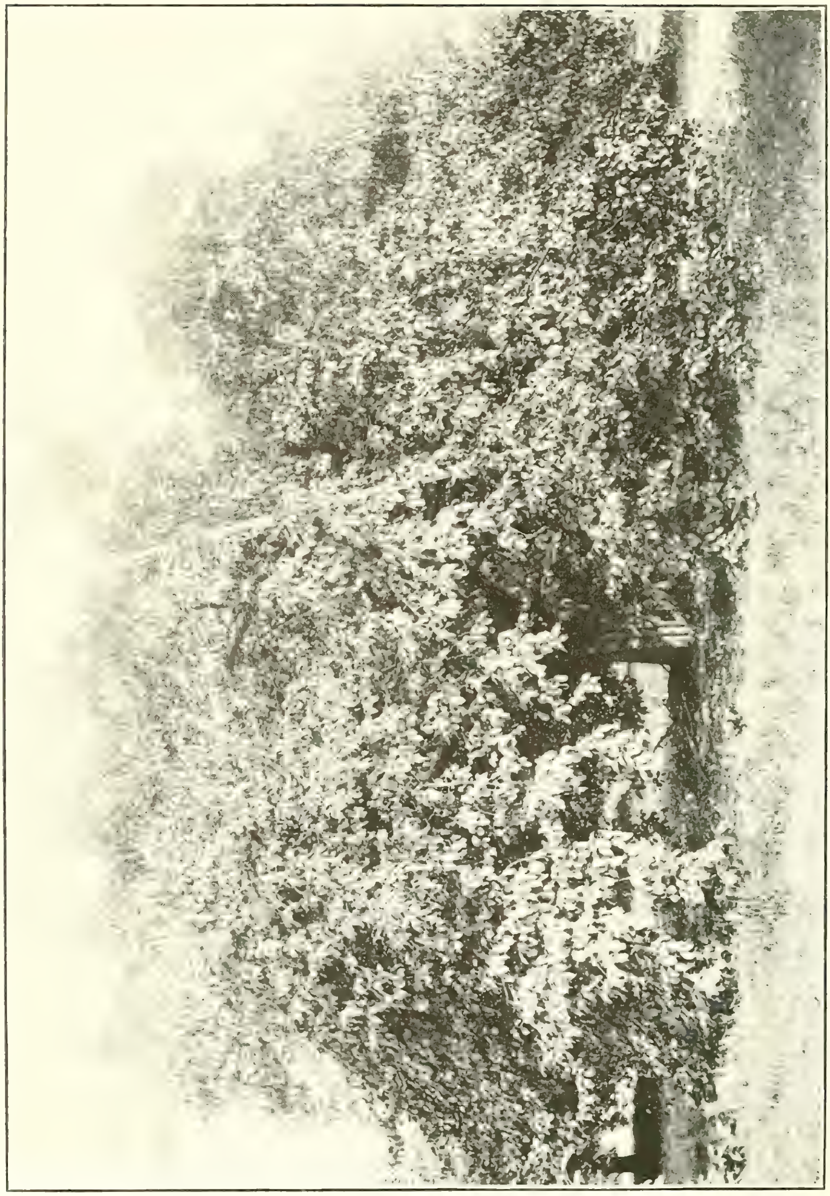
MISCELLANEOUS NOTES ON SOIL-VARIETAL ADAPTATION.

In the eastern part of Massachusetts with its near-by markets summer and fall varieties of apples such as Williams (Williams Favorite), Red Astrachan, Maiden Blush, Oldenburg (Duchess of Oldenburg), Wealthy, etc., are grown with much success on Gloucester loam and Gloucester fine sandy loam. The predominating reason for growing these and other early season varieties in eastern Massachusetts is, however, except in the case of Wealthy and to some extent Oldenburg, the local or near-by market demand, rather than the character of the soil, which also happens to be favorable. This is shown by the fact that, with the exception of Wealthy, which has been much used as a filler in recent plantings, these varieties are little grown in western Massachusetts, even though they give good results there on the same or similar soils.

It may be added that Red Astrachan under ordinary or average conditions maintains a stronger growth for a longer term of years on the Gloucester series than on the average Wethersfield soils. This is strongly indicated by the productiveness of old trees or of trees more than 25 years old. It seems probable that the arrest of growth

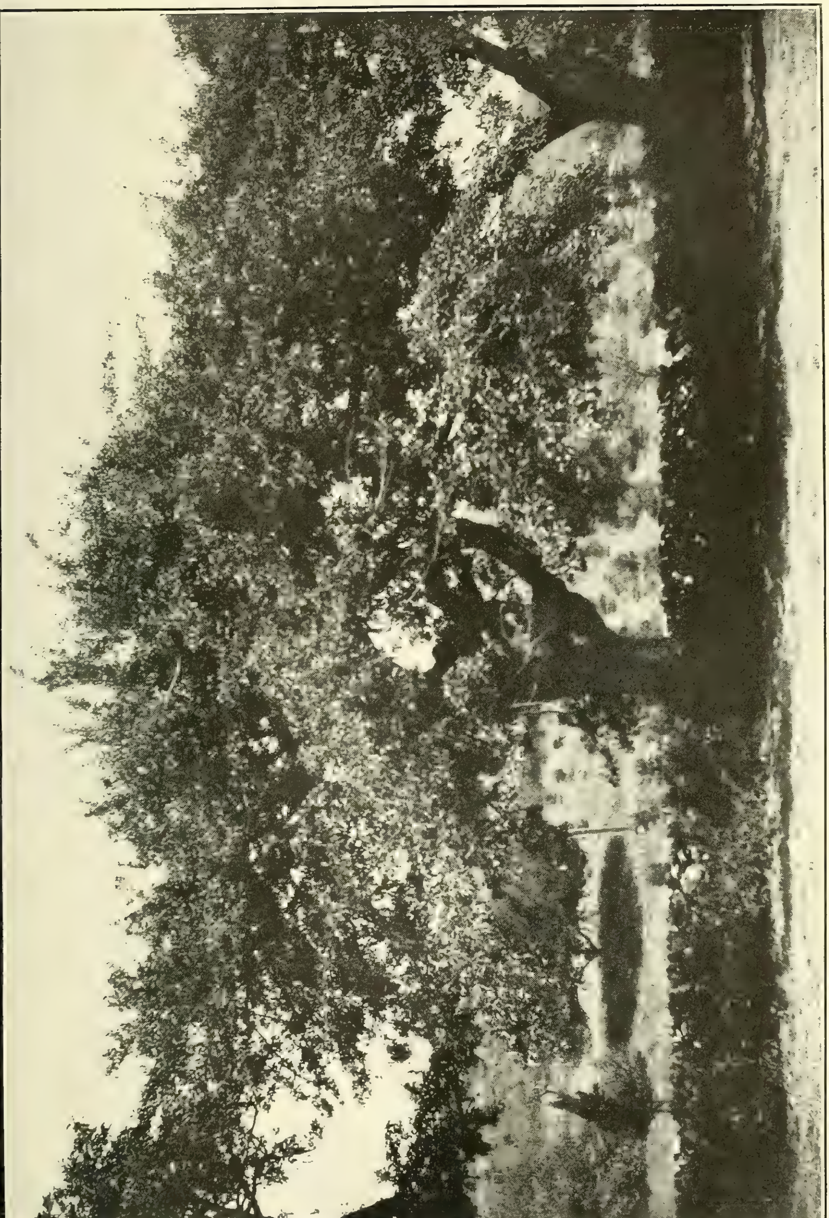


McIntosh, 7 Years Planted, Bearing Third Crop. Gloucester Loam, Fitchburg, Mass.



GRAVENSTEIN, 45 YEARS OLD, ON WETHERSFIELD LIGHT SILT LOAM.

[Top cut back and thinned. Note severe thinnings of fruit on the ground. Heavy yield and good quality.]



INDIVIDUAL TREE IN PLATE V.

[Roxbury Russett, 96 years old. Long lived and prolific on strong loam. Newbury (Oldtown), Mass.

SIX-YEAR CARMAN PEACH ON VIRGIN WETHERSFIELD LOAM. WALLINGFORD, CONN.

during a droughty period affects these sorts more severely than the stronger growing varieties such as Baldwin, and under equal conditions the Gloucester loam certainly maintains a more uniform moisture supply than the Wethersfield loam, though not necessarily more than deep areas of the less extensive Wethersfield silt loam. Undoubtedly other of the weaker-growing, or short-lived, sorts will also do better under the same treatment on the average Gloucester soils than on the Wethersfield; but strong-growing varieties such as Wealthy and McIntosh are very promising on the loam, silt loam, and heavy phases of the sandy loam in the Wethersfield series, except at low elevations in southern Connecticut, and on them Baldwin has long since proved its worth for commercial purposes.

THE ADAPTEDNESS OF SOILS TO VARIETIES OF PEACHES.

If a line be drawn connecting the northernmost of the commercial peach orchards in Connecticut it will correspond in a general way to the most southern of the average isothermal lines (U. S. Weather Bureau) of the six winter months which includes any material part of the State. During the spring months of March, April, and May the fluctuations of the extremes of temperature are also a little less marked within this belt where, at good local elevations, the minimum temperature does not reach the point of frost as frequently as elsewhere in the State, and winter temperatures are likewise a little less severe. This effects a relative steadiness of temperature during critical periods which lessens the danger from frost. The line referred to would extend just north of the southwest corner flange of the State, where it projects into New York, northeasterly about 10 miles north of South Norwalk, thence to Beacon Falls and Farmington, across the Connecticut Valley north of Hartford to Vernon, south to East Glastonbury and Haddam, and thence to the southeast corner of the State. Within the area lying between this line and the Sound most of the commercial peach orchards of Connecticut are located, though comparatively little development has taken place east of Haddam where it may be said the weather records seem a little less favorable, and in the southwestern extension of the State orchards are scattering.

On the Gloucester soils of the Western Highlands is located, however, one of the largest commercial orchards, and there are many smaller ones in both the highland districts. The importance of good local elevation can hardly be overestimated. Even in an average season the rotting of fruit is much worse in orchards where the free and rapid circulation of the air is in any way impeded, and in a season such as 1912 when the weather was hot and humid during part of the picking period, the tendency is much increased. The soils in the areas where development has chiefly taken place are distributed among four main series, the Wethersfield, the Middlefield, the Gloucester, and the Talcott, named in the order of their importance. There are various types of soil in each of these series as determined by texture, and a wide range in what may be termed general soil or field conditions. The Wethersfield and the Middlefield series are underlain by shale or sandstone at varying distances from the surface, and under equivalent treatments are not quite so strong for general farm crops as the Gloucester soils.

The fact that peach growing has not been developed more extensively in the highlands is doubtless due primarily to climatic conditions, as the opinion prevails, founded in part at least on experience, that the crop is a little less certain there than within the isothermal line mentioned. Aside from the prolongation of the isotherms northward in the Central Lowland their usual direction is northeast and southwest, and if the three southern New England States be considered as a unit the isothermal lines roughly parallel the seashore. The close relationship existing between the temperature lines covering the southern Berkshire hills in the Seymour district, the Woodstock district, in the northeast part of the State, and that locality in southeast Worcester and western Norfolk Counties, Massachusetts, where peach growing is commercial, is very striking. As successful orchards are maintained on the Gloucester soils in all these districts, it would seem that the somewhat prevailing opinion that the Wethersfield soils are superior to the Gloucester soils for peach production is based on the average texture of the series, and that the real difference is largely one of soil type rather than of soil series.

It is doubtless true, however, that under good treatment a given type—as the loam—of the Gloucester series is a little stronger than the loam of the Wethersfield or the Middlefield series, and hence a given variety of peach as grown on it tends to ripen a little later than on the corresponding soil type of either of the two latter series. For this reason these different series as represented by the different soil types require different treatments to maintain a normal balance between the vegetative and the fruiting habits of the tree. This is a matter requiring skill in observation, and knowledge as acquired through experience of the way the soils respond to different treatments; and the subject merits further study. It may be said, however, that certain soil conditions seem fundamental. For example, soils should be so deep and friable that any excess of free moisture not only disappears readily below the root zone of the trees but returns to that zone as capillary soil solution for the trees' use as occasion may make desirable. Anything interfering with such free movement of the soil moisture, which by the absorption of soluble matter within the soil becomes the soil solution which the trees use, is a detrimental soil condition. Underlying ledges, large stones, the several kinds of hardpan, and subsoils that are too impervious because of excessively fine texture (too clayey) or stiff structure, are of this class and should be scrupulously avoided.

Again, the textural and structural relationship between soil and subsoil may be of considerable importance. With surface soil of strong loam, for example, a subsoil of light sandy loam or even of compact sand is preferable to a loam or a clay loam, as it offsets in a measure the more retentive tendency of the surface material; and while such a soil section is probably less desirable than a strong sandy loam underlain by a friable loam, or approximate material, it has given good results, nevertheless, in several instances. It is a matter of common experience, however, in various peach districts, that where both soil and subsoil consist either of sand or of heavy material the best results are not secured. In a given case where a small part of a large orchard is a sand or a very light sandy loam it is very difficult to secure a growth as strong as desired largely on account of the difficulty of keeping up the supply of humus. But the subsoils that are in a general way satisfactory in both texture and structure are extremely variable, and to the countless combinations of these characteristics not all varieties respond equally well. For a description of some of the individual types of soil upon which peach growing has been most extensively developed the reader is referred to page 23.

In general, slightly moist soils seem less objectionable for the white varieties at present grown in southern New England than for the yellow sorts, a high finish on the latter being more difficult to secure on soils which tend to be moist. This is evidenced in some orchards on Wethersfield soils where underlain by a somewhat impervious layer at a depth of 15 to 24 inches. This layer consists of a mass of shale fragments embedded in heavy silt loam or silty clay loam, the shale being so dense as to prevent the use of a soil auger, and it in turn is usually underlain by bed rock. This soil is sufficiently impervious to delay cultivation for a few days in the spring after adjoining areas without the hardpan are ready, and all varieties ripen appreciably later. These soils are not so impervious, however, as to cause any hydration, the soil being a clear red and of open friable structure throughout. It is thus apparent that the excess moisture, while disappearing slowly, eventually does so sufficiently to prevent any hydration and to afford thorough aeration and oxidation later in the season. Several of the white varieties are grown satisfactorily, but the yellow sorts rarely have as good finish and the quality, in some cases, at least, is inferior to that secured on other soils.

The unfavorable weather conditions which prevailed during the peach-harvesting season of 1912, especially in the Carman-Champion period, furnished in conjunction with subsoil variation an unusually sensitive index to the behavior of these varieties and also to some other sorts.

The tendency of the Champion peach, when humid weather prevails, to rot before quite ripe enough to pick, is generally recognized as a very serious difficulty with this otherwise excellent variety. The connection between the direct effect of the weather in bringing this about and any impervious condition in the subsoil, as determined by hardpan, underlying rock, a too high content of clay, or a subsoil structure too stiff is quite marked, and was of much commercial importance in Connecticut in 1912. So exacting were the weather conditions that it was very difficult, and in some cases impossible, especially in the large orchards to prevent more or less loss no matter how favorable the soil and local elevation, but the fruit went down much more rapidly where the subsoils were shallow or lacked sufficient porosity from some one or more of the causes above enumerated. This was somewhat noticeable when comparing the fruit from different orchards, but as such comparisons are usually based upon the average of the soil and subsoil conditions which often include a considerable range, they are much less indicative than similar contrasts afforded by an orchard or orchards under the same management, where it is certain that the same or comparable treatments have been given, or where information is available as to the exact variation in the treatment for a considerable term of years.

The influence of variation in soil depth was well illustrated in the season of 1912, on a ridge of about 500 feet elevation in a large commercial orchard, which is divided by a north and south road. On the east side of this road Carman and Champion were both later, as in other years, than on the west side, the elevation being virtually the same. On the west side the soil is friable and of fairly good depth. As the underlying rock dips to the east, it is much less broken than on the west side and consequently subsoil drainage is far less complete. The friable soil—Wethersfield silty loam—does not vary materially to an approximate depth of 2 feet, but because of the difference in subsoil drainage that west of the road may be worked from a week to 10 days earlier in the spring than that east of the road, and there is a similar difference in the ripening date of a given variety of peach. On August 31, for example, the Champions still needed to ripen for several days, and stray Carman trees were only just ready to pick, though the Carman season was supposed to have ended in that locality a week before. In this case all conditions except the subsoils are so nearly identical that the difference seems due solely to the greater retentiveness of the one, the extra moisture thereby retained so lowering the specific heat of the subsoil as materially to defer the ripening of fruit or other products. If there be excessive humidity just before picking time, however, this additional moisture may cause the fruit to go down more quickly than that from subsoils less retentive of moisture.

Judging from the experience of a very large number of growers in Connecticut and in other States, combined with field observations, it seems evident that the Champion peach is especially sensitive to any condition of subsoil which hinders the ready movement of moisture within a probable depth of as much as 4 feet from the surface. This would include not only those conditions which tend toward hardpan, but also the subsoils whose clay and silt content is sufficient to render them compact or close, particularly the clays and the clay loams.

While the surface soil should not be heavy enough to form clods, its character is of much less importance than that of the subsoil.

Notwithstanding the fact that a fairly strong soil is desirable for the best tree growth and size of fruit, it is very easy so to overdo these tendencies that the fruit neither matures well nor ships well. If the picking season happens to be wet the rotting tendency of Champion is increased and such a season is almost fatal to this variety when grown on rich strong ground. So it seems that Champion is best planted on soils of only medium productivity, but they should be sufficiently loamy and deep for the variety to be held well within control. There should be not too much humus, yet just enough. The soil and subsoil should be held so closely in hand that a little fertilization will increase the size of the fruit if necessary, and conversely that the fruit may be held in check if the shipping quality is not satisfactory. The best results, averaging seasons, have come from light porous soils such as medium to heavy friable sandy loams underlain by material not heavier than a friable loam, and preferably by a heavy sandy loam. Too great porosity of the entire soil section may entail, however, more risk from droughty periods than would appear from rot on a soil section a little heavier, hence soils may be too sandy and loose even for the Champion.

Carman and Mountain Rose are not quite so dependent as the Champion on soils that drain out hastily, and while they succeed best on soils of a little greater moisture-holding capacity than the Champion, they nevertheless give the best results on deep and well-drained soils. They do very well indeed on the Wethersfield loam which seems for them a typical soil condition. They are also grown with success on heavy sandy loams and on the light silty loams of the Wethersfield series and the Middlefield series where the subsoil is not more compact than a friable loam or light silty loam. (See Pl. XXI.)

The Elberta and the Belle (*Belle of Georgia*) thrive on well-drained soils that are somewhat stronger than the varieties previously mentioned. The wood is said to be less brittle than that of some other varieties, and hence suffers less from breaking down. Loams, silty loams, and silt loams with subsoils of similar material seem not too heavy, nor to supply any excess of moisture provided the entire soil section is well drained. These varieties do not ripen as early locally on such soil types as on those more sandy, but in most cases earliness is of little importance with these varieties as compared with a better development of fruit. While the Elberta and the Belle, in common with other varieties, are best grown on deep soils, they are somewhat less sensitive to shallow soil conditions than are such varieties as Champion or Carman, though no variety grows so well on shallow soils, and in general they will stand stronger fertilization and greater amounts of organic matter in the soil than will Champion or Carman.

Late Crawford also seems to thrive best on a fairly strong soil such as a light porous loam, one that is a little less retentive of moisture than the heaviest of the Elberta soils mentioned.

Some of the early varieties, such as Greensboro, are less sensitive to shallow soil conditions than others, this probably being due, in part at least, to the inferior quality of these early sorts as compared with later varieties.

SUMMARY.

The surface features of Massachusetts and Connecticut are locally complex, but they may be grouped as follows to show general relationships: The Western Highland, the Berkshire Valley, the Connecticut Valley, the Eastern Highland, and farther east in Massachusetts the Eastern Plateau, the Framingham-Boston Lowland, and the coastal district, which includes Cape Cod.

The climate is rigorous, but the seasons are of sufficient length for the securing of good farm crops. The climatic conditions are very favorable for apples in both States. Peaches are successfully grown in several localities, but the chief development is along the high slopes adjoining the lower Connecticut Valley Basin.

The upland soils have been derived from glacial drift, except possibly on a few of the steep and narrow preglacial ridges early denuded of all glacial débris. The soils are thus composite in character. Large and important areas of sedimentary soils occupy the Connecticut Valley and alluvial soils also occur along many of the minor streams.

There is a wide range of soils in Massachusetts and Connecticut, which vary greatly in productivity. Poor soils occur, but there is a large total acreage of good soils which are in part well farmed and in part so poorly managed that they bear the reputation of being low in productive quality, or even worn out. The latter soils need first to be located and classified, and then to have their farming possibilities demonstrated by experimental crop growing.

A general soil classification follows:

The Gloucester series is by far the most extensive. It includes the yellow and brown upland soils. The gray and blue-gray upland soils constitute the Bernardston series. The Wethersfield series includes the glaciated upland areas of Triassic red standstone and shale, the surface soils of the sandy types being gray or pinkish gray, and the heavier types red or salmon in color. The subsoils are red or salmon. The Middlefield series includes the glaciated upland areas of Triassic yellow and gray sandstone and shale, the surface soils being yellow, brown or gray, and their subsoils brown to yellow. The glacial outwash soils found along the lower courses of streams as they issue from the uplands into the major valleys constitute the Merrimac series. The Dover series consists of glaciated limestone soils in the Berkshire Valley. The Whitman series occurs in depressed or basin-shaped areas, and also bordering streams. The surface soils range from brownish gray to almost black, while the subsoils are lighter gray, or mottled gray and yellow. The Essex series consists of dark-brown glacial soil underlain by a light-brown to yellow subsoil usually lighter in texture than the surface soil.

The agricultural methods pursued in the market gardening sections, and in other districts of special crop development, are intensive, but in the general farming districts extensive methods prevail.

Even in this long settled region there is need for improvement in the agricultural and horticultural practice. Growers of special crops—onions, tobacco, market-garden produce, apples, peaches, cranberries, etc.—are generally prosperous. Other farmers who prosper are those who retail the milk produced on their own farms, poultrymen who have placed their business on a firm footing notwithstanding frequent individual failures, and dairymen who have produced some money crop or product, such as apples, potatoes, garden produce, poultry, etc. Few farmers prosper, on the other hand, unless an income is secured from some special money crop or product.

In the hilly districts some farms have properly been abandoned because they did not furnish, under current agricultural conditions, a sustaining basis for a prosperous family. Other farms that have always possessed the possibility of a good livelihood if efficiently managed have been abandoned on account of family circumstances. The first class of lands should be managed by the owners of the second class—that is, as adjuncts to farms now existing as economic units—or they could be so combined in some cases as to form new economic units of land holdings. There are good opportunities in both States for such land development, but they must be developed on the basis of economic adaptedness of the different soil conditions to crops and other farm products.

There is little land tenantry in either State. Most farms are occupied by their owners, but those owned by city residents are often occupied by managers and superintendents.

Labor conditions do not differ from those in other northeastern States. The cost of labor has steadily increased, thus necessitating more efficient farm management—a goal not infrequently attained.

The principal products sold are horticultural crops from field and greenhouse, milk and cream, poultry and eggs, veal and pork, tobacco and onions.

In districts intensively farmed the adaptedness of soils to crops is pretty well understood and the cropping system is generally well arranged. In the districts where extensive methods of farming prevail, adaptedness of the soil to crops is less generally recognized.

Trunk-line and branch railways, with many trolley lines, furnish good transportation facilities for most of the region, though some districts are still far from such advantages.

The area of Massachusetts is 8,039 square miles, and in 1910 her population was 3,366,416, or 418.7 per square mile. The area of Connecticut is 4,820 square miles, and in 1910 her population was 1,113,736, or 210.5 per square mile. Such a mass of population furnishes excellent markets for large quantities of farm-food products.

Soil development along various lines is possible. Among these, orcharding is important.

The different varieties of apples and peaches do not succeed equally well on all soils, some varieties giving the best results on soils or under soil conditions that may be more or less definitely defined. In some cases, however, a soil not suitable in all respects may be modified, as by increasing or decreasing the humus content, tile draining, etc., to meet the requirements to such a degree that moderately good results may be secured. The kinds of soil upon which various varieties of apples have given, and may reasonably be expected to give, good results are described.

Under cultivation mellow loams and fine sandy loams overlying subsoils not lighter than a medium loam nor heavier than a light or medium clay loam of friable structure excel for the Baldwin. Under the same soil conditions Rome Beauty thrives farther south, where the climate is a little warmer. Heavy silty loam or light silty clay loam with similar subsoil brings a good "green" Rhode Island Greening, but lighter soils such as fine sandy loams and warm mellow loams excel if a high blush is desired.

Soils favoring the Hubbardston are rich fine sandy loams, or heavy loamy fine sands with subsoils of fine sandy loam or mellow loam.

For the Northern Spy and the Wagener, a mellow medium loam underlain by heavy loam or friable light clay loam is desirable, but the supply of humus and the application of ammonia-carrying fertilizers should be much greater for the Wagener than for the Northern Spy.

The heavier of the soils described for the Baldwin seem promising for the McIntosh.

For Tompkins King and Gravenstein, an open-textured loam, rather than a fine loam, with subsoil of the same or only slightly heavier texture, is preferred. While similar soils are excellent for Ben Davis and Gano, it is believed that these varieties should be grown outside of New England.

Both the Tompkins King and the Northern Spy soils give good results with the Fall Pippin.

A deep rich loamy soil with subsoil of at least medium porosity, preferably a sandy loam, is excellent for Roxbury.

Soil adaptedness under Connecticut conditions to some of the commercial varieties of peaches follows:

Champion succeeds best on soils of only medium productivity, but they should be deep and well drained. Medium to heavy friable sandy loams underlain by material not heavier than a friable loam and preferably a heavy sandy loam are very desirable.

Carman and Mountain Rose succeed best on soils somewhat less pervious than the Champion, but still deep and well drained. This soil condition seems typically supplied by the loams of the Wethersfield and the Middlefield series.

The Elberta and the Belle prefer stronger soils than the Carman and the Mountain Rose. Loams, silty loams, and silt loams, with subsoils of similar material seem best to meet these requirements under Connecticut conditions.

For Late Crawford, a fairly strong soil, such as a light porous loam somewhat less retentive of moisture than the heaviest of the Elberta soils is desirable.

Some of the early varieties, such as Greensboro, are less sensitive to shallow soil conditions than the varieties mentioned above.

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THE CLYDE SERIES OF SOILS.

By J. A. Bonsteel,
Scientist in the Soil Survey.

INTRODUCTION.

The surface soils of the Clyde series are dark gray, dark brown, or black in color. The subsoils are gray or sometimes yellowish in color and mottled with yellow and gray, but not with red, in practically all cases. The surface of nearly all members of the series is level, with only slightly rolling or ridged areas where some of the types rise above the general level of the surrounding country. In nearly all of the more extensive areas of their occurrence, and in all of the smaller tracts, the surface of the different soils of the Clyde series is depressed below that of surrounding soils of other series. The soils of the Clyde series have been formed either by direct deposition as sediments in old glacial lakes, which have since been drained by natural processes, or they have resulted from the accumulation of more or less mineral matter and a large amount of partially decayed organic matter in small lakes, ponds, and swampy depressions occurring within the glaciated region of the northeastern and north-central States. In the majority of instances the larger areas of the soils of the Clyde series occur within more or less well-drained basins of old glacial lakes.

The soils of the Clyde series grade into deposits of muck and peat on the one hand and into the more completely drained soils of other series of the glacial lake and river terrace province, or of the glacial and loessial province, on the other.

Note.—This bulletin discusses the origin, characteristics, and uses of the Clyde series of soils; it is suitable for distribution in New York, Ohio, Indiana, Michigan, and Wisconsin.

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Another distinction which is of general but not quite universal application, is that the subsoils of the different types of the Clyde series, particularly the subsoils of the more extensive and heavier loam and clay soils, have been found to be calcareous. Many analyses of these subsoils have been made, which disclose from approximately 1 per cent of lime carbonate to as much as 25 per cent of that material. Usually the more sandy members of the series are not so well supplied with lime carbonate as the heavier textured types.

In their natural condition practically all the different soils of the Clyde series in all occurrences which have been encountered are rather poorly drained. They require artificial drainage to become of agricultural use but are then very productive soils for the growing of the staple farm crops of the region in which they occur and for the production of special crops where market facilities are favorable.

GEOGRAPHICAL DISTRIBUTION.

All of the known occurrences of the soils of the Clyde series are localized within the territory immediately to the south of the Great Lakes. The largest areas are to be found in the Maumee Valley in Ohio and Indiana; in the valley which stretches to the southwest from the shores of Saginaw Bay, in Michigan; and along the shores of the St. Clair River, Lake St. Clair, and the Detroit River in southern Michigan. The latter region is a connecting strip between the two larger areas. In addition there are considerable areas of soils of the Clyde series in northern and western New York, associated with the glacial lake deposits of the St. Lawrence River Valley and the Lake Ontario Plain; in northern and central Indiana, associated with the great glacial river terraces of the Kankakee and other rivers; and in southeastern Wisconsin, in a glacial lake area which extends from the southern end of Green Bay to the vicinity of Fond du Lac. (See fig. 1.) These areas include all of the most extensive localities within which soils of this series have been encountered, and within which additional large areas may be expected to be mapped as the work of the Soil Survey progresses.

There are, however, many smaller isolated areas of the soils of the Clyde series which are found in the smaller basins, drained lake areas, and swampy terraces of glacial outwash material which occur throughout the upland portions of the States bordering the Great Lakes. Although such areas may be individually of limited extent, their aggregate area will ultimately be found to be very large.

In addition many small disconnected areas of the soils of the Clyde series are found in low hollows and depressed level areas within the glaciated upland of the region immediately south of the Great Lakes, particularly in western Ohio and eastern and central Indiana. These areas represent tracts where the local drainage was

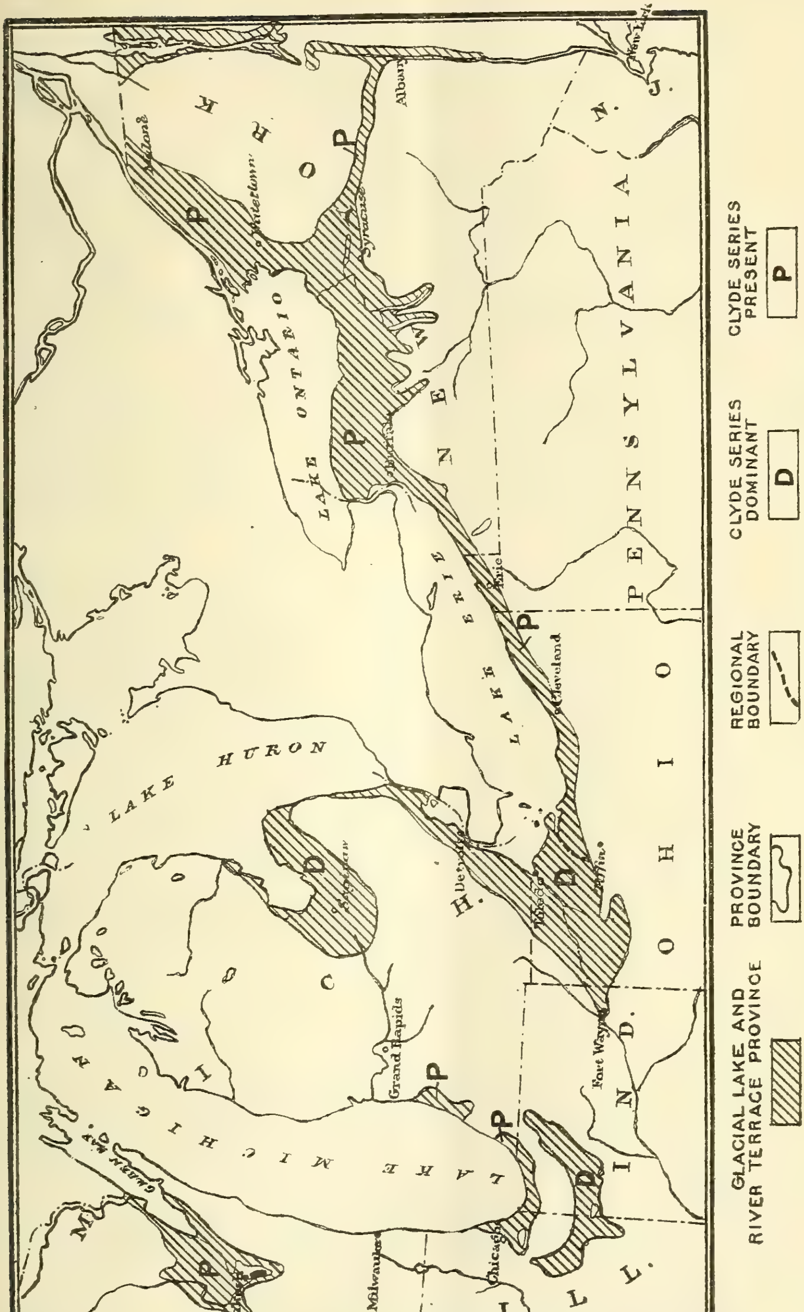

FIG. 1.—Sketch map showing regions in which the Clyde soils are found.

obstructed and where considerable accumulations of organic matter were mingled with the surface soil. Before artificial drainage was supplied the majority of them existed as swamps and swales irregularly scattered through the upland. Artificial drainage has brought about the reclamation of the majority of these tracts, and their soils are now classed chiefly with the Clyde series.

Expressed in terms of parallels and meridians, the territory within which some members of the Clyde series have been encountered extends from longitude 75° west to longitude 90° west; and from latitude 40° north to latitude 45° north. There is some probability that more northern occurrences will eventually be encountered. It should be understood that the larger areas of soils of the Clyde series are decidedly localized within these geographic limits, being confined to those portions of the territory which were at one time occupied by the glacial lake extensions of the Great Lakes, or else occurring within smaller lake beds and depressions throughout the upland or upon the terraces of the glacial rivers which once furnished outlets for the ponded waters of the predecessors of the present Great Lakes system.

THE GLACIAL LAKE AND RIVER TERRACE SOIL PROVINCE.

The various sections of the country may be divided into major soil provinces within which the soil-forming materials possess a common general origin and have been deposited or otherwise formed through very similar processes. That region in the northern portion of the United States which was at one time or for successive periods of time occupied by the waters which resulted from the melting of the continental ice sheet and those portions of the lower lands across which these ponded waters escaped to the sea are classed as the glacial lake and river terrace province. Its general location and extent are shown upon the map, figure 1.

GEOLOGICAL ORIGIN OF THE SOILS OF THE CLYDE SERIES.

Within recent geological times a large proportion of the northeastern and north-central States was occupied either once or repeatedly by a thick covering of ice in the form of a continental glacier. The latest occupation by glacial ice has been called the Wisconsin stage of glaciation by the geologists. It took the form of a glacial advance in many ice lobes occupying the area now covered by the existing Great Lakes and the adjacent territory immediately to the south and west of them.

The different lobes of ice were pushed southward from the Canadian highlands until they occupied practically all of northern and western New York, northwestern Pennsylvania, northern Ohio, and

Indiana, all of Michigan, northern and northeastern Illinois, nearly all of Wisconsin, and large areas in Minnesota and Iowa.

The form of the ice lobes and the general direction of their advance seem to have been greatly influenced by the basins now occupied by the Great Lakes. Thus, in the St. Lawrence Basin one of the more eastern lobes was deflected by the Adirondack Mountain mass, reaching its most southern limit at altitudes of 1,500 to 2,000 feet above the present sea level where its southward spread was terminated against the highlands of southern New York and northern Pennsylvania. The extreme southwestern portion of this lobe extended to northeastern Ohio, where it terminated at elevations of approximately 1,000 feet above sea level, occupying the rolling plain which forms the northeastern extension of the Mississippi Valley. Other lobes covered all of the southern peninsula of Michigan and extended across the low plateau of northern Ohio and Indiana, of northeastern Illinois and southeastern Wisconsin, terminating on the low plain of the upper Mississippi Valley at altitudes varying from 700 to 1,200 feet above sea level.

In practically all instances this latest advance of the continental glacier occupied territory which had previously been glaciated one or more times. During the period of its advance and occupation of this territory the Wisconsin glacier redistributed the unconsolidated material which already existed within the region, filling many of the deeper valleys which had been cut into the underlying rock. It also brought fresh material from the Canadian Highlands and from the more northern portions of the north-central States. In addition it derived a considerable amount of material from the local rock over which it passed. All of this material was deposited either during the occupation of the region by the glacial ice or during the slow northward recession of the ice sheet.

The material thus deposited usually consisted of a heterogeneous mass of coarse and fine particles derived from many diverse sources and laid down either in the form of ridged moraines, where the ice front was stationary for a considerable period of time; in the form of gently rolling till plains, where the glacial material was deposited beneath the ice in the form of ground moraine, or as stratified sand, gravel, and bowlder deposits where streams of water flowed from the ice front, or from caverns formed between the land surface and the ice.

As a result of these differences in the character of glacial action the general land surface of the area occupied by the ice was first smoothed by the glacial erosion of exposed surfaces, then further leveled by the filling of protected depressions through the deposition of glacial materials. Yet the final land surface maintained a considerable degree of irregularity in surface elevation through a failure to obliterate the previous relief of the country and through the deposition to unequal thickness of the different classes of glacial materials.

The recession of the glacial ice during this latest state of glaciation undoubtedly occupied a long period of time as measured in years. It was accompanied by the formation of large volumes of water derived both from the melting of the ice and from the normal annual precipitation over the region. This water was forced to seek outlets to the sea through new channels cut across the moraines and till plains of the north-central States and through channels formed along the border between the ice and a higher lying upland which had been freed from its ice covering in the northeastern States. During the progress of the establishment of these new drainage ways there was an extensive ponding of the glacial waters within the lower lying areas included between the ice front and the elevated land areas of different characteristics which lay to the southward. This stage of deglaciation resulted in the formation of several large bodies of glacial lake waters along the southern limits of the present Great Lake system and of innumerable small glacial lakes held between the more elevated moraines and in depressions in the till planes of the glaciated upland.

The larger glacial lakes occupied successively lower levels along the ice front as the ice retreated, since successive channels opening to the sea were uncovered during the long period of glacial recession. Owing to this frequent change in level the students of glacial geology have been able to identify a large number of different glacial lakes which have been given different names. In some instances as many as 10 or 12 different stages of glacial lake occupation, possessing different outlets and giving rise to characteristic glacial lake sediments at many levels, have been identified.

For the purposes of the discussion of the glacial lake deposits which ultimately gave rise to the soils of the Clyde series it will hardly be necessary to outline the different areas occupied by even the larger successive glacial lakes. It will be sufficient instead to outline in a general way the largest areas within which these deposits were formed, to indicate the sources of the material which gave rise to this particular group of soils as distinct from other soils of somewhat similar mode of formation, and to show the processes through which the different soils of the Clyde series have been created.

It is probable that the first glacial lakes formed along the border of the receding ice occupied small areas around the southern extremity of Lake Michigan, where glacial Lake Chicago was formed, and a small area extending from the vicinity of Fort Wayne, Ind., eastward across the State line into Defiance, Paulding, and Van Wert Counties, Ohio, where the first stage of Lake Maumee existed. With a slow recession of the ice sheet the area of glacial Lake Chicago was increased, covering what is now the southern end of Lake Michigan. In consequence, only small areas of glacial lake material now form the land surface around the southern extremity of that lake. In the case of Lake Maumee the gradual recession of the ice gave rise to the formation of glacial lake materials covering an area of more than 4,000 square miles in northwestern Ohio, northeastern Indiana, and southeastern Michigan. In fact, the entire Maumee Basin and the adjacent territory, extending from the vicinity of Fort Wayne, Ind., past Sandusky, Ohio, on the south and to the vicinity of Port Huron, Mich., on the north, was occupied by a succession of glacial lakes whose characteristic topography and distinctive soils now constitute the principal surface features of that region.

At the same time a considerable area of low-lying land to the south and west of Saginaw Bay, in Michigan, was occupied by glacial lake waters at several successive periods. It is probable that the total area formerly occupied by glacial lake waters around Saginaw Bay amounts to approximately 2,500 square miles.

A similar area was occupied by glacial lake waters standing at the lower levels around the head of Green Bay, in Wisconsin, and southwest past Fond du Lac. The total area of glacial lake sediments in the latter region is possibly as great as 1,000 square miles.

During these earlier stages of ice recession and glacial lake occupation the outlets for the ponded waters were through the Des Plaines River into the Illinois River, for Lake Chicago; past Fort Wayne into the Wabash River, for the first Lake Maumee; and around the "thumb" of Michigan through Lake Saginaw and thence down the Grand River to Lake Chicago for the more northern waters. As the ice still farther receded, a passage for the impounded water was uncovered to the eastward between the ice front and the higher lying plateau country of northwestern Pennsylvania and western New York. For a time, at least, an outlet was established through the Mohawk Valley, while at a later stage the drainage way through the St. Lawrence River was uncovered. Still later, marine waters occupied the St. Lawrence Valley and a small area around the outlet of Lake Ontario. Thus a series of glacial lakes was formed along the southern shores of Lakes Erie and Ontario and within the St. Lawrence Valley.

FORMATION OF GLACIAL LAKE DEPOSITS.

During all of these successive stages of glacial lake occupation, distinctive lake sediments were deposited at the different levels, descending from an altitude of about 800 feet for the higher stages of the more western lakes to the present level of the upper Great Lakes. In the more eastern areas south of Lake Ontario the elevated plateau at the south maintained the first glacial-lake stages at altitudes as high as 1,100 feet in the Finger Lake region of central New York, while the later more extended glacial lakes in western New York occupied areas lying below 800 feet in elevation and thence declining to an altitude of 246 feet, the present elevation of the surface of Lake Ontario. At all of these elevations continuous or interrupted areas of lake sediments were deposited.

The materials which were reworked and redeposited as glacial-lake sediments were everywhere of diverse origin. They were derived immediately from the heterogeneous mass of stone, gravel, sand, silt, and clay which formed the glacial till. This mass of earthy matter existed either upon or in the ice mass and was set free by melting or it had previously been laid down by the ice in the form of moraines and other deposits. In some localities it is possible that the glacial lake waters also derived some material from underlying consolidated rocks where these were not covered by glacial deposits. Such occurrences were of very small extent.

In general, the largest amounts of material were contributed either by the glacial streams which flowed directly from the ice, by streams which flowed into the glacial lake basins from the uncovered but previously glaciated uplands, or through the direct action of waves and currents of the glacial lakes upon the till which formed the boundaries or the floor of the glacial lake basins.

The streams which were formed directly from the melting of the ice carried glacial materials of all sizes, which were sorted and deposited either in the form of long, low ridges chiefly consisting of gravel and sand, which are known as eskers, or as broad, low outwash plains usually sandy in their general character. In both cases the finer sediments were carried to positions more remote from the ice front and were deposited in the deeper and quieter waters of the glacial lakes.

Similarly the streams which flowed into the glacial-lake basins from the deglaciated uplands brought large amounts of material and this was partially or completely assorted to be deposited in the form of stream deltas near the outer margin of the lake areas. Frequently the coarser material was dropped in the form of low alluvial fans where the stream waters entered the lake. The finer materials from these sources were also carried to greater distances and deposited with the finer sediments derived directly from the glacier. There was thus a mingling, in the majority of instances, of upland glacial till, of local country rock material, and of materials contributed directly through the melting of the glacial ice, all deposited to form the different grades of glacial lake sediments.

Along the landward border of each of the larger lakes wave action played a considerable part in eroding both the glacial till and in some cases the local country rock. This resulted in the formation of wave-cut terraces at the higher levels and in the deposition of sandy and gravelly beaches and bars concentrically around the margins of the lakes at different elevations corresponding to the different levels of the receding glacial lake waters.

The materials formed in the deltas of both glacial and upland streams and the material deposited along the shore lines usually constitute the coarser grained sediments of glacial lake deposition. It is in such areas that large stone and coarse gravel are most frequently encountered, while only smaller gravel and the different grades of sand are found in the outwash plains and in those portions of the stream deltas which were carried farthest into the lake areas. Elsewhere the finer grained sediments, such as sandy loams, loams, and clays, prevail.

In the smaller glacial lake areas, particularly where lake occupation existed only for a brief period, the finer sediments dominate.

In the case of all of the larger glacial lakes irregularities in the surface of the glacial till, accentuated in some instances by the existence of local belts of moraine, gave rise to very unequal depth of water within the lake area. In the case of the glacial Lakes Saginaw and Maumee, curved moraines, concentric with the lake-shore line, rose above the lake level at some period of the lake stage. The waters of the lake acted against these moraines in the same manner as against the upland till, forming beaches and distributing the coarser and finer sediments along these shore lines and through the deeper lake waters. Other portions of the till and of water-laid moraines rose nearly to the surface of the lake and the crests of these submerged ridges were subjected to a degree of wave action only less than that along the shore lines. In certain areas the force of the water was only sufficient to move and redistribute the finer grained particles, while the larger gravel and the bowlders remained practically in their former position, being somewhat accumulated at the surface through the removal of the finer earthy material. Where such action has taken place unquestioned glacial lake deposits sometimes present the anomaly of abundant glacial bowlders and of large cobblestones. In some instances it is even difficult to distinguish between glacial moraine or till and the feebly reworked glacial sediments derived through the action of shallow lake waters across ridges which rose nearly to the surface of the lake.

In other instances the drumlins and other glacial till ridges extended above the surface of the lake waters and only their sloping flanks and the lower lands between them were covered by glacial lake sediments.

In every instance in the larger glacial lake basins the silt and clay derived from the different sources outlined were deposited in the deeper and quieter lake waters in positions more remote from the deltas of tributary streams and at some distance from shore-line borders. They usually rest either upon consolidated rock, upon glacial till, or upon the more sandy or gravelly materials which were sometimes deposited first as the ice retreated.

Thus the greater part of all of the glacial lake basins consists of marginal gravelly and sandy zones, of local sand plains and stream deltas, and of the heavier loam and clay deposits more remote from the sources of sedimentary supply.

When the waters of the different glacial lakes were gradually withdrawn and the bottoms of these lakes exposed to form a land surface there were many minor inequalities of elevation which gave rise to wide differences in the drainage features of the lake basins.

Areas lying between successive beaches frequently remained swampy. Shallow depressions in the broader lake plains still contained minor ponds and swamps. Only the higher lying areas and the more sloping surfaces became well drained immediately after the recession of the glacial lake. The broad level areas, occupied by the heavier clays and loams, together with all depressed areas within the glacial lake plains, remained swampy for a considerable period of time. In consequence large areas included within the glacial lake basins passed through a swampy stage which persisted in many instances until the occupation of the land by white settlers, and which has only been relieved to a partial extent through the installation of artificial drainage.

It is probable that water-loving grasses and the smaller forms of vegetation first occupied these swampy areas. It is certain that considerable areas of the swamp included within the glacial lake basins remained so poorly drained until within historic times that only a few species of trees found foothold within their limits, while in many instances considerable areas remained in the condition of treeless marshes or grass-grown swales.

In other instances areas somewhat better drained eventually became covered with a heavy stand of ash, elm, soft maple, tamarack, and other water-loving trees. In all cases the swampy conditions gave rise to the formation of large amounts of humus in the surface soil and this has given a characteristic dark gray, brown, or black color to the surface layer of extensive areas of the glacial lake deposits in the north-central and northeastern States. These give rise to the soils of the Clyde series. Conditions of more perfect drainage gave rise to light-gray or yellow surface soils which are classed in other soil series than the Clyde.

The different soils of the Clyde series, therefore, owe their origin to a complex series of events beginning with the glaciation of the northeastern and north-central States, followed by the retreat of the continental glacier and the formation of large or small glacial lake and glacial stream terrace areas, which in turn was succeeded by the withdrawal of the lake waters and the formation of extensive swampy, or at best poorly drained areas within the lake basins, and ended by the accumulation of considerable amounts of partially decayed organic matter in the surface soils.

The soils thus formed have been rendered capable of agricultural occupation only through the installation of artificial drainage in the majority of cases. Many thousands of acres of these soil materials still remain poorly drained.

TOPOGRAPHIC RELATIONSHIPS OF THE SOILS OF THE CLYDE SERIES.

The greatest development of the glacial lake province in New York State occurs from the vicinity of the St. Lawrence Valley westward along the shore of Lake Ontario to the Niagara River.[1] In the St. Lawrence River counties the area within which the glacial lake sediments are developed is narrow, forming a belt varying from 5 to 15 miles in breadth along the shore of the river. Its surface is anything but smooth and the irregularities are due to the different elevations of the consolidated underlying rocks, which present an uneven and sloping surface, as well as to unequal deposition of the glacial till. Over materials of diverse origin and of uneven altitude the sediments of the glacial waters were deposited to greatly varying depths.

In general, the lowest elevations occur along the shore of the St. Lawrence River and around the eastern end of Lake Ontario. The surface of the sedimentary lake deposits consists of large and small level tracts which are interrupted by ridges of rock, by swells of moraine, and by hollows within which swamps still exist. Gradually this uneven surface rises toward the Adirondack border until the highest distinctly glacial lake deposits are found about 750 feet above sea level or about 500 feet above the waters of Lake Ontario and the St. Lawrence River.

Throughout this section of the glacial lake region there has been a sufficient degree of obstruction to surface drainage to give rise to the formation of swamps of large and small size, resulting in the formation of soils of the Clyde series. They are always to be found in locally depressed positions, which are not so poorly drained as the associated swamps but which are less well provided with natural drainage facilities than the surrounding upland soils. Many of the areas also accumulate local seepage waters from soils or rock areas lying at higher elevations.

[1] Bulletins Nos. 106, 127, and 145 of the New York State Museum. Glacial Waters in the Lake Erie Basin. Glacial Waters in Central New York. Geology of the Thousand Islands Region. By H. L. Fairchild and others.

A considerable part of the soils of the Clyde series in this section consists of the heavier clays, while smaller areas contain enough coarser material to constitute the Clyde fine sandy loam and fine sand.

The largest area of the glacial lake deposits of New York State extends from the vicinity of Syracuse to the Niagara River and from the southern shore of Lake Ontario to the bordering highlands which pass through the western portion of the State at a distance, roughly, half way between the Lake Ontario shore and the southern boundary of the State. From Syracuse to Buffalo, N. Y., the upper limit of the lake sediments lies approximately along the line which marks an elevation of 1,000 feet above sea level. At higher altitudes there were only local lake deposits, while even below the 1,000-foot contour line there are many higher lying ridges and hills which were probably not covered by lake waters for a sufficient period of time to give rise to distinctively glacial lake deposits.

This portion of the glacial lake province is also marked by great differences in altitude and surface configuration. Along the shore of Lake Ontario the surface of the land lies at 250 to 300 feet above tide level or approximately from the level of the lake to elevations of 50 feet above its waters. Thence a narrow belt, ranging from 10 to 15 miles in width from north to south, lies in the Lake Iroquois plain, formed at the latest stages of glacial lake occupation. This area slopes gently downward from altitudes of 430 feet to the shore of the lake. It is usually bordered at the higher altitude by a gravelly and sandy shore line. Other minor ridges of a similar nature extend in a generally parallel direction with the present shore line and at positions intermediate between the higher shore line of the glacial Lake Iroquois and the present shore of Lake Ontario.

From Oswego County westward, and particularly in Wayne and eastern Monroe Counties and in the region immediately south of them, there are numerous lenticular hills (known geologically as "drumlins"). They are also found through the lake plain region at all elevations as far west as Erie County, N. Y. They rise to maximum elevations of 150 feet above the adjacent lowlands and will probably average an altitude of 75 to 100 feet in elevation along their crests. They consist of glacial till and are merely surrounded in the majority of instances by the sedimentary deposits of the several glacial lake occupations of the general territory.

The lower lying land areas, lake sediments in the main, consist of very similar materials reworked by glacial waters and redeposited. The surface of the majority of areas of this character is remarkably flat or uniform in slope in the area which was covered by the glacial Lake Iroquois. The greater part of the sediments of this body of water lie in such positions as to be fairly drained, except in the extreme western portion of the area in Niagara County. As a result only small and scattered occurrences of the soils of the Clyde series are found.

From the vicinity of Rochester, westward nearly to the eastern border of Niagara County, there are rolling plains and low rounded swells which show little or no evidences of having been covered for any length of time by lake waters. These till areas contain no included deposits of soils of the Clyde series so far as the region has been mapped in detail.

The country which rises southward from the 430-foot contour line, the approximate shore line level of the glacial Lake Iroquois, to altitudes of 1,000 or 1,100 feet is varied in its topography. At first the surface does not materially differ from the lower plain. There are larger areas of the rolling swells of till, many drumlins in the eastern section, and a sharp break between the lower plain and the upper as the vicinity of Lockport, N. Y., is approached. There the lower plain is separated from a higher plain of very similar character and soil development by the first evidences of the rock-formed Niagara escarpment over which all of the waters of the Great Lakes pour at Niagara Falls. This escarpment first appears as a low ridge of limestone which becomes more elevated to the westward where it takes the form of cliffs or ridges. At its base lies the old shore line of Lake Iroquois, along its slopes and cliffs the bare rock outcrops, while at its summit the lake sediments again make their appearance and stretch for many miles to the southward, covering the greater part of the country west of the Genesee River and east of the Niagara up to an elevation of 800 feet above sea level. This higher plain is the area which was occupied by glacial Lake Warren and it forms an extension to the east of the glacial lake areas which were developed at about the same geological time in the Maumee Valley of Ohio and the Saginaw Valley of southern Michigan.

The upper plain is much diversified in its surface slopes and drainage features in western New York. The southern portion of Niagara County, the northern part of Erie County, and the adjacent portions of Orleans and Genesee Counties contain large areas of nearly level land with very slight depressions, which have been the location of former swamps, and within which considerable areas of the soils of the Clyde series have been accumulated. Other swampy areas have become the location of deposits of muck and peat.

In the case of all of the larger areas of soils of the Clyde series in extreme western New York the surface is depressed below the general level of the surrounding soils, and the types of this series are poorly drained and darkened by accumulations of organic matter only less in amount than is required to constitute muck soils.

The lake deposits of this section were prevalently fine grained and the heavier soils of the Clyde series are quite extensively developed.

There are also areas in Niagara County where underlying till deposits reached nearly to the surface, but were thinly veneered with lake sediments, and maintained for a long period of time in a partly drained condition. On such tracts there is a scattering of field stones of glacial origin which is unusual with any soils of the Clyde series. Probably a part of these stones have reached their present position through having been brought to the low ridges and stranded by the melting of floating ice. Others have been separated from the till by wave action which redistributed the finer grained materials locally as lake sediment and left the stones in a prominent position at the surface. Such areas give rise to the stony phase of the Clyde loam.

Throughout the entire region of the glacial lake deposits in New York State limestone rock underlies a considerable part of the plain. It has contributed mechanically divided limestone to the glacial till and both directly and indirectly to the lake sediments. Even where both of these classes of material overlie noncalcareous rocks there is a perceptible admixture of limestone fragments of all sizes in both the unstratified materials and the sedimentary deposits. This furnishes the small or large percentage of lime carbonate which is associated with the subsoils, at least, of the majority of the types of the Clyde series.

up to an elevation of 800 feet above sea level. This higher plain is

In extreme western New York, from Dunkirk to the western boundary of Chautauqua County, in the northwestern portion of Pennsylvania, around Erie, Pa., and in northeastern Ohio, around Ashtabula, the glacial lake plain is very narrow, measuring not more than 3 to 5 miles in breadth from Lake Erie southward. Only small areas of the soils of the Clyde series are found in this region.

From the vicinity of Sandusky, Ohio, westward nearly to Fort Wayne, Ind., and thence northeastward to the vicinity of Port Huron, Mich., lies an extensive area which was occupied at several successive stages by glacial lake waters. The oldest of these glacial lakes has been named Lake Maumee. This was succeeded by Lakes Whittlesey and Warren. The latter occupied a portion of the higher lake plain in western New York as well as the lower portion of the glacial lake plain in northwestern Ohio and adjacent portions of Michigan.

It is probable that the waters of these several glacial lakes did not occupy the Maumee Valley for any great period of time, yet it is certain that they were present for a sufficient period to establish very definite shore lines on the landward side. These shore lines have been traced accurately through northern Ohio, northeastern Indiana, and southeastern Michigan.[1]

The lower limit of the glacial lake sediments which were formed in this basin is at present marked by the shores of Lake Erie and of the St. Clair River, Lake St. Clair, and the Detroit River. This lies at an altitude of about 575 feet above sea level. The highest limits of occupation by the glacial Lake Maumee are found to be approximately 775 feet above tide in the vicinity of Fort Wayne, Ind., about 800 feet in the southeastern counties of Michigan, and ranging from 750 to 800 feet above sea level in north-central Ohio. There is thus a total difference of present elevation of the surface of these glacial lake deposits not exceeding 225 feet. The Maumee Basin thus presents a very gently sloping surface which is inclined from the level of the shore lines toward a central axis extending from Fort Wayne, Ind., to Toledo, Ohio, with a gentle slope toward Lake Erie along the line of this axis. The slopes are so slight over any limited area that it is difficult to determine their direction except by the aid of leveling instruments. The stream-drainage ways are deeply cut along the major streams but follow mere shallow trenches so far as the majority of tributaries are concerned. The Maumee River has cut its channel to a depth of 15 to 60 feet, frequently encountering bedrock. The smaller streams have cut their courses from 10 to 40 feet below the level of the plain.

The general surface of the lake plain in the Maumee Basin is but slightly undulating over the upland between the drainage ways. Low swells and ridges rise to altitudes of 5 to 20 feet above the lowest points in any given locality. There are also low moraine ridges of somewhat greater elevation which probably rose above the level of the ponded lake waters. The Defiance moraine in the extreme northwestern counties of Ohio thus separates all of the basin lying in Allen County, Ind., and a large part of the lake sediments found in Defiance, Paulding, and Van Wert Counties, Ohio, from the remaining area of the Maumee Basin.

Below the highest shore line of the glacial lake waters there are usually two or more other shore lines existing as concentric ridges of gravelly and sandy material frequently separated from each other by sandy loam or loam deposits. Elsewhere through the Maumee Basin the greater part of the surface consists at present of the dark-brown or black clay loam or clay soils of the Clyde series.

The chief exception to this rule is found along the immediate banks of the Maumee River and its principal tributaries where erosion has removed the shallow lake deposits, exposing the underlying till in the form of yellow or brown clay loam soil, classed with the Miami

[1] Glacial Formations and Drainage Features of the Erie and Ohio Basins, U. S. Geol. Surv. Monograph No. XLI. By Frank Leverett.

series. There are included areas of swamp and muck, which occupy a small aggregate percentage of the region. The limestone rock which underlies a considerable proportion of this basin also reaches the surface in the form of local rock outcrop. There are a few small areas where the glacial till is exposed or where it was covered to such a shallow depth by the glacial lake waters that distinctive lake or swamp deposits were not formed. It is probable, however, that 75 per cent of all of the soils found within the area of the Maumee Basin have been formed, at least at the surface, through the deposition of lake sediments and through an unusual accumulation of organic matter under succeeding swampy conditions. Frequently the subsoil and deeper material consist of a gravelly glacial clay, classed as till by some authorities and as glacial lake material mixed with ice-borne fragments by others.

The northern extension of the glacial lake deposits in the Maumee Basin was undoubtedly connected along the southwestern shore of Lake Huron with a similar area which surrounds the present Saginaw Bay in east-central Michigan. The shore-line features are continuous, the sediments deposited are almost identical, and the lake plain extends as a narrow border along the eastern shore of the "thumb" of Michigan.

The extensive lake plain which lies to the south and west of Saginaw Bay was occupied by another glacial lake, which has been called the glacial Lake Saginaw. It is certain that its upper stages were continuous and contemporaneous with the upper stages of the glacial lake waters of the Maumee Basin.

The highest beach level formed by this lake in the Saginaw Basin lies at an elevation of about 850 feet above sea level in the vicinity of Flint, Mich. This is at an altitude of about 260 feet above the waters of Saginaw Bay, and the present area in the Lake Saginaw Basin thus possesses a fall of approximately 250 feet from the old shore lines to the present shore line. The concentric beaches around the margin of this embayment lie at several levels and are usually marked by sandy and gravelly deposits, between which sandy loam material prevails. The central portions of the area are somewhat more undulating than in the case of the Maumee Basin and considerable areas are occupied by low morainic ridges whose crests were apparently about at water level during the later stages of glacial lake occupation. It appears that extensive deposits of sandy and gravelly material were formed within the limits of the lake basin as delta material from the streams which flowed into Lake Saginaw, both from the glacial ice, forming the northeastern boundary of the lake and from the exposed till upland forming its border to the south and west.

While there are very extensive deposits of unquestioned lake sediments within the area of the glacial Lake Saginaw, there are also numerous large areas where the glacial till remains uncovered by glacial lake materials or is so thinly covered that only portions of the present surface may be confidently ascribed to glacial lake deposition. Some of these deposits, because of the large amount of partially decayed organic matter in the surface soil and because of their evident previously swampy condition, are more closely related to the soils of the Clyde series than to any other group. Others, not so marked, belong to other soil series. The glacial outwash materials and many of the beach line deposits do not contain sufficient organic matter to give them the characteristic dark color of the Clyde soils.

Because extensive water-laid glacial moraines are closely associated with and partly covered by the glacial lake deposits some members of the Clyde series are found to be gravelly or stony in the Saginaw Lake area.

In general the surface of the Lake Saginaw area is undulating to gently rolling, although considerable areas, extending northeast from Saginaw along the south shore of Saginaw Bay, are very flat and unrelieved. In consequence, a considerable proportion of this glacial lake area is fairly well drained through the deep-cut channels of the larger streams. Other portions, because of level topography and lack of natural stream ways, have remained swampy until recent years.

Another glacial lake area of limited extent was formed in southwestern Michigan, northern Indiana, northeastern Illinois, and southeastern Wisconsin around the southern end of Lake Michigan. This was known as the glacial Lake Chicago. The majority of the deposits within this area do not form soils which are included in the Clyde series. However, in a narrow belt extending along the western shore of Lake Michigan from the vicinity of Racine, Wis., nearly to Chicago, Ill., the soils of the Clyde series occupy the greater proportion of the old glacial lake bed. In this area the soils of the Clyde series are found from the shore line of Lake Michigan to altitudes of 60 feet above its present level, at which elevation the shore line of the ancient glacial lake stood. This belt of territory ranges from 2 to 5 miles in width. The highest land within it frequently lies near to the present lake shore, declining gently inland for a distance of 1 or 2 miles and then rising rather sharply to the old shore line. At the higher elevations more sandy soils are found, while in the depression the soils of the Clyde series prevail.

Surrounding Green Bay and Winnebago Lake and extending southwestward past Fond du Lac, Wis., occurs another area which was occupied by glacial lake waters. The highest shore line which bounds this area lies at a level of 800 to 820 feet above sea level, or 220 to 250 feet above the present level of Lake Michigan. In general, the surface of the lake sediments in this area is level or gently undulating, although ridges of till rise above the lower lying glacial lake material. As in the case of the western New York areas and the Saginaw Bay area, other glacial lake sediments occupy considerable areas within this region, yet the lower, more level, and poorly drained sections where organic matter has accumulated extensively are occupied to some extent by soils of the Clyde series. As in the case of the majority of the other localities where soils of this series are found, limestone rock underlies a considerable proportion of the glacial lake embayment around Lake Winnebago and Green Bay. It has been reworked to some degree into the glacial till and into the glacial lake sediments derived from the till.

It is probable that an examination of the Upper Peninsula of Michigan will show small areas of the Clyde soils lying at the lower levels around Lake Huron and along the southern shore of Lake Superior. The necessary conditions of local calcareous rock, of glaciation, and of the deposition of glacial lake sediments followed by swampy conditions after the withdrawal of glacial lake waters all exist in the eastern end of the northern peninsula of Michigan.

The occurrences of the Clyde series thus far outlined all lie within the larger glacial lake basins surrounding the present Great Lakes. In addition there are hundreds of smaller glacial lakes which existed in the upland areas, outside of these larger basins, in western New York, southern Michigan, northern Indiana, and southern Wisconsin particularly. In many instances these small glacial lakes have become drained or have been partly filled with accumulations of both mineral and organic matter. In such instances smaller areas of the different soils of the Clyde series have frequently been formed. Such is the case in many of the southern counties of Michigan and of the southeastern counties of Wisconsin.

Another characteristic mode of occurrence of the soils of the Clyde series is found along the old glacial drainage lines through which the ponded waters of large and small glacial lakes found their outlet across the divides. In many instances these drainage channels now exist as broad river valleys cut through the glacial till where the present streams are bordered by one or more broad, flat, and frequently poorly drained river terraces. Wherever drainage has been sufficiently obstructed to give rise to temporary swamp conditions there has been considerable accumulation of swamp vegetation, contributing organic matter to the surface soil. In some instances this accumulation has been sufficient to constitute a normal soil rendered dark brown or black at the surface. In the latter cases considerable areas of different soils of the Clyde series have been formed.

The largest single area of this description occurs in northwestern Indiana and northeastern Illinois along the banks of the Kankakee River. From the southern boundary of Michigan to Will County, Ill., this river is bounded by a level terrace area which was probably formed as the bottom of a local glacial lake but which has since been drained by the cutting down of the lower reaches of the Kankakee River. The present land surface lies at an elevation from 10 to 30 feet above the normal level of the river. The area constituted a vast swamp in the early days, but has been partially drained and occupied. Its surface is only relieved by low ridges of sand which in many instances resemble lake-shore deposits but in other cases are evidently sand dunes.

A considerable part of the terraces along the Kankakee River is occupied by the more sandy members of the Clyde series. Other portions consist of muck and peat, of sand dunes, and of undrained swamps.

There are many other instances where smaller areas of soils of the Clyde series are found within the old glacial terrace deposits along the courses of streams once occupied by a greater volume of water than at present. Certain of these areas of the Clyde series are found far to the south of the glacial lake areas within which the greater part of the Clyde series soils occur.

Numerous small areas of soils of the Clyde series are also found in depressions throughout the glaciated uplands of western Ohio and northern Indiana.

TYPE DESCRIPTIONS.

CLYDE SAND.

The Clyde sand has only been encountered in the southern peninsula of Michigan, where five soil survey areas have included portions of this type. By far the largest area, amounting to more than one-half of the total, occurs in Allegan County, Mich. Here the type occupies 38,600 acres, while the total area surveyed in the State amounts to 67,400 acres. It is probable that the extension of soil surveys in this general region will show a much larger total area of the type, occurring in low-lying and poorly drained locations where sandy glacial outwash was accumulated under ponded and swampy conditions.

The surface soil of the Clyde sand to an average depth of 12 inches or more consists of a medium to fine grained, black, sandy loam, well supplied with partly decayed organic matter. The subsoil varies in the different areas from a gray or white sand to a gray silty clay. In almost all cases the surface soil is immediately underlain by a layer of gray or white sand of medium to coarse texture to a depth of 2 or 3 feet from the ground surface. This is, in turn, underlain by a heavier and more silty or claylike deep subsoil which is very retentive of moisture.

Not infrequently a small amount of fine gravel is found, intermingled with both the surface soil and subsoil. It does not usually interfere with the cultivation of the soil and is not so abundant nor so generally present as to make any appreciable difference in the relationships of the soil type to moisture.

The Clyde sand is always found in level tracts which are depressed below the general level of the surrounding uplands and in positions where either glacial outwash or later soil wash from sandy upland areas has accumulated under conditions of poor drainage. There are no elevations or irregularities of surface which would interfere with cultivation. Frequently the areas occupied by the Clyde sand still receive wash from higher lands, and they also receive a considerable amount of seepage water from adjacent porous soils of greater elevation.

Practically all areas of the Clyde sand are found to be in a swampy condition when first occupied, and many areas have remained unreclaimed by artificial drainage. As a result of this condition large amounts of vegetable matter in a partly decayed state have accumulated in the surface soil, rendering it black in color and loamy in texture. Similarly the drab or gray color of the subsoil is an indication of poor natural drainage. The excess water held in the subsoil has excluded the air, and there has been little or no weathering and oxidation of the iron-bearing minerals of the subsoil. Where drainage has been partly established the subsoil colors are tinged with yellow or brown.

Wherever the Clyde sand has been occupied for the more intensive forms of agriculture it has been necessary to establish open ditches for the outlets of extensive tile underdrains or in connection with smaller open farm ditches. In its natural condition the Clyde sand supports a thick growth of water-loving trees and of swamp grasses. In such localities its chief economic use is as pasture. Only when artificial drainage has been installed is the type well suited to crop production.

Where the Clyde sand has been properly drained it has been successfully occupied for the production of the general farm crops, of which the yields are moderate. Corn is one of the most extensively grown and important crops. The large amount of organic matter in the surface soil, the ease with which a good moisture supply is maintained, and the easy tillage of this soil tend to make it one of the best of the sandy soils for corn production. In fact, its position and natural drainage features combine to retain more soil moisture than would otherwise be possible in such a porous soil. It ranks more nearly with the sandy loam upland soils than with sand soils for these reasons. The general average of corn yields upon the Clyde sand ranges from 20 bushels per acre, usually where drainage is defective and the stand is reduced by excess moisture, to 35 bushels per acre or more where drainage has been established and the organic matter content of the surface soil has been carefully maintained through the application of stable manure. Corn is grown both for the grain and for silage, and the yields of silage range from 8 to 10 tons per acre. While the type is a fairly good corn soil it is not so well suited to this crop as are the heavier members of the series.

Oats are also grown in regular rotation with corn and grass. The large amounts of organic matter in the surface soil and the high moisture content tend toward an excessive growth of straw, and this is frequently weak and unable to support the grain crop to maturity. The yields are frequently reduced through losses from the lodging of the grain. Where drainage is fully established good yields are secured. The yields of oats range from 25 to 40 bushels per acre. Sometimes the partly matured crop is cut for hay when the lodging is so marked as to indicate that grain production would be impossible or unprofitable.

Hay constitutes one of the most extensively grown crops upon the Clyde sand. Even where the drainage is not sufficiently established to insure good grain crops it is adequate for the growing of timothy or of mixed timothy and alsike clover. Areas of this character are seeded down and frequently left in grass for a period of three to five years or more. Hay is cut during the earlier years of the seeding, and the land is pastured when the hay yield falls below 1 ton per acre. In other wetter areas the wild grasses are cut for hay or utilized for pasture. In the cultivated fields the yields of mixed hay range from 1 to 1½ tons per acre. The average yield of the wild grasses cut for hay is not over 1 ton per acre. The pastures upon this soil are usually well maintained during the dryer months of summer because of its low-lying and partially drained condition. Grass production upon the Clyde sand should be one of its chief uses where it is not so situated nor so well drained as to render it available for the growing of the more intensely farmed crops.

Wherever the drainage conditions in the different areas of this soil have been perfected the Clyde sand is especially well adapted to the growing of special crops. When markets are accessible these crops should constitute the chief dependence of agriculture upon this soil. Sugar beets are successfully grown upon the higher lying and better drained portions of the type, giving yields of 10 tons or more per acre. The sugar content is high and this soil is probably the best sandy soil upon which to grow the crop. Care should be exercised to provide perfect drainage, and to maintain the organic matter content of the soil. The beets should be grown but one year upon any given field, as crop rotation is essential to obtaining the best yields.

Early Irish potatoes give fair yields of tubers of good quality. The yields range from 100 to 150 bushels per acre. In growing the potato crop perfect drainage is essential to success, as otherwise danger from blight and scab is great. The use of large quantities of high-grade commercial fertilizer is requisite. The most successful potato growers use as much as 500 to 1,000 pounds per acre of a fertilizer which analyzes about 2 to 3 per cent of nitrogen, 8 to 10 per cent of phosphoric acid, and 7 to 9 per cent of potash, derived preferably from sulphate of potash. Frequent shallow cultivation is required during the earlier part of the growing season. The spraying of the crop to reduce damage from blight is not common, but should be generally adopted upon this low-lying and moist soil type.

In the vicinity of some of the larger cities, where the local market is good, other market-garden crops are grown upon the Clyde sand. Cabbage, onions, cauliflower, tomatoes, cucumbers, and string beans are thus produced in the vicinity of Saginaw, Mich., and the crops obtained are very profitable. Only a small area of the Clyde sand has yet been utilized for such crops and the extension of market gardening upon the type is dependent chiefly upon increased market outlets rather than upon the development of unused areas of the soil. Many thousands of acres may be used for these intensively farmed crops when the demand arises. A field of onions on the Clyde sand is shown in Plate I, figure 1.

The Clyde sand may be characterized as a soil fairly well suited to the growing of general farm crops where drainage has been installed, for pasturage where drainage is only partial, and for the growing of market garden crops and sugar beets where the local market for these crops exists and where the type has been completely drained.

There are thousands of acres of this soil which are but partially reclaimed at present and which constitute a reserve of easily worked, special-purpose farm land still awaiting utilization.

In general the farm equipment upon the Clyde sand does not differ materially from that of the general region where it is found. The market-garden farms are usually of rather small area and are frequently only equipped with a small residence and with sheds or small barns for the housing of work stock and tools. The general farms upon the type are usually improved with the larger house and the large barns common to the grain and dairy farms of the Central States. The type is susceptible of efficient tillage with rather light teams and tools, and these are used for the more intensive forms of cultivation. In fact much of the work of the market-garden farms is performed by hand after the land has been fitted by horse labor for the planting of the various crops.

CLYDE GRAVELLY SAND.

The Clyde gravelly sand has only been encountered in two areas, both occurring in the southern peninsula of Michigan. Its total extent amounts to only 24,656 acres as mapped to the present time. Its most characteristic occurrence is in the vicinity of Saginaw, Mich., where it is found along old beach lines of the glacial Lake Saginaw, and in low slopes along bases of the surrounding glacial hills. It is found in Allegan County, Mich., in the form of low, rounded gravelly hills and as the chief soil of the low terraces which border the Kalamazoo River in that county.

The surface soil of the Clyde gravelly sand to an average depth of about 10 inches is a medium-textured, dark-brown, loamy sand, marked by the presence of a considerable proportion of medium to fine gravel. The subsoil is rather coarse, incoherent gravelly sand which is either underlain by gravel, as in the case of the river terraces, or grades into coarse sand and gravel at a depth of about 2 to 3 feet. Usually clay is found at a depth of 4 to 6 feet.

The surface soil always contains a sufficient amount of partly decayed organic matter to give it a characteristic dark-brown or nearly black color and to render it somewhat loamy. The type, as a whole, is fairly well drained owing to its sloping position on upland areas and to the near presence of drainage ways on the river terraces.

The general farm crops of the region where it occurs are chiefly grown upon the Clyde gravelly sand. Corn produces fairly good yields ranging from 25 to 35 bushels per acre. It is found necessary to use stable manure freely upon this rather porous soil in order to secure the larger yields. It is not a typical corn soil and other crops are better suited to it.

Among the small grains both rye and buckwheat produce fair yields. They are more commonly grown than either wheat or oats and are better adapted to this soil. Rye yields 12 to 15 bushels per acre, and buckwheat 15 to 20 bushels. Oats give only small yields in normal years, owing to the fact that the soil does not retain a sufficient amount of moisture to supply the needs of the crop at the time of the formation of the grain. Either rye, which matures earlier, or buckwheat, which is a late summer crop, should be preferred to oats.

While there is some difficulty in securing a good seeding of mixed grasses, clover gives a good seeding and excellent yields. Mixed hay produces an average of about 1 ton per acre, while clover alone yields from 1 to 1½ tons per acre at the first cutting with a possible second crop for seed. Red clover is chiefly grown, although the alsike clover is also well suited to production on this soil.

Some difficulty is experienced in securing a good stand of sugar beets and they are grown only to a very limited extent upon the Clyde gravelly sand. Beans give fairly good yields.

The Clyde gravelly sand is so thoroughly drained that the longer-growing field crops are not so well adapted to production upon it as the early truck and small fruit crops. As yet, these are scarcely grown at all since the chief areas of the type, as found, are not especially well situated with regard to markets. Considerable areas of the type are not occupied agriculturally.

CLYDE FINE SAND.

The Clyde fine sand has been encountered in eight different soil-survey areas, located in New York, Indiana, Illinois, and Wisconsin. A total area of 74,048 acres has been mapped of which 68,480 acres are found along the terraces bordering the Kankakee River in Newton County, Ind., and Will County, Ill. The other areas are small and of little agricultural importance.

To an average depth of 10 inches or more, the surface soil of the Clyde fine sand is a dark-gray to black, medium to fine sand. It is always heavily charged with partly decayed organic matter and not infrequently grades into included areas of peat. In such cases the organic matter is found to extend in large quantity to depths of 3 feet or more. In other instances, near the margins of sandy islands and bars, which rise above the general level of the Clyde fine sand, there are bordering areas where the dark-colored surface soil is only about 4 to 6 inches deep. In some localities over the more level portions of the type, sandy areas with a shallow covering of organic deposits are also found. The subsoil is a gray sand which varies from dark color near the surface to a lighter gray or ash color at greater depths. The subsoil is sometimes mottled with brown or yellow stains. At the greater depths the sandy subsoil frequently becomes somewhat compact and sticky through the presence of larger proportions of silt and clay. The type is stone free in both soil and subsoil and even gravel is of rare occurrence.

In all of the smaller areas of its occurrence the Clyde fine sand occupies small depressions within the area of other sandy soil types and owes its existence to the deposition of large amounts of organic matter where natural drainage was deficient. These areas mark the former existence of small glacial lakes, ponds, and succeeding swamps within upland areas or associated with other glacial lake deposits. In the chief occurrence along the terraces of the Kankakee River, in northern Indiana, the Clyde fine sand has been formed as a sandy deposit of the glacial predecessor of the present river, whose flood plain was many miles in width and probably consisted of ponded glacial waters at one or more stages of the development of the drainage way. It would be unusual to encounter such a large area of such uniformly assorted sand in the channel of any very active stream and it is more probable that the present channel represents stream excavation followed by the ponding of water and the deposition of the sand as sorted material derived from a variety of sources and laid down to some extent by the tributary streams as well as by the major stream which later occupied the valley.

The Clyde fine sand, in Newton County, Ind., occupies a strip of territory south of the Kankakee River, having a breadth of 10 to 12 miles. It extends across the boundaries of the county both to the east and to the west and a similar strip of soil is found on the north bank of the river. The area surveyed in Newton County comprises only a small proportion of the total area of the type as it occurs along the Kankakee River.

Near the river the surface of the Clyde fine sand lies at elevations of only 5 to 10 feet above the normal stream level. There is a gentle rise away from the river which rarely amounts to more than 1 or 2 feet per mile and the appearance of the river terrace is that of a very level plain which is only relieved through the irregular occurrence of sandy ridges, rising in the form of old shore lines or sand dunes above the general level. These have altitudes of 10 to 30 feet above the surrounding plain. It is along the flanks of these ridges that the Clyde fine sand reaches its highest elevations above the river and where it was best drained under natural conditions. Shallow depressions are also found in the plain within which the swampy conditions have so long persisted that accumulations of peat or muck were formed, having a depth of a few inches to many feet. Otherwise the broad, nearly level river terrace is occupied chiefly by the Clyde fine sand.

For a long period of time, during the settlement of the region, the plain occupied by the Clyde fine sand remained in a swampy and almost impassable condition. More recently extensive ditches have been opened by the counties involved and into these the local farm drainage is led. In the majority of instances the drainage is still accomplished by open ditch, but a beginning has been made in the tile underdrainage of the land. This should be extended over the entire area, since it is the only permanent and completely satisfactory method by which these lands may be brought to their full producing capacity.

Drainage still remains so imperfect over considerable tracts that the farm buildings are located upon the sandy elevations which rise above the general level of the plain. Many local swamps persist and the peat areas have been but recently drained. Both from the standpoint of profit and of health drainage should be extended and rendered more complete.

The crop adaptations of the Clyde fine sand vary considerably in the different areas where it has been encountered. In the most extensive area, in Newton County, Ind., the crop uses vary chiefly with the proportion of organic matter found in the surface soil and with the depth of the dark-colored surface soil. Those areas in which the organic matter content is rather small are chiefly devoted to pasturage, while the areas well supplied with vegetable remains to a considerable depth are used for the production of general farm crops.

Corn is the principal tilled crop grown. It is reported that in the early days of the occupation and cultivation of this soil the yields secured were as high as 50 bushels per acre. It is now estimated that the average yield is about one-half of this amount. Present yields range from 10 to 35 bushels per acre. Corn is grown for one or more years and the land is then seeded to a small grain crop, almost always to oats. Oats yield from 20 to 30 bushels per acre. In the usual rotation the field is next seeded to grass. Timothy is commonly sowed alone as clover is likely to be winter killed on the level and partly drained land. It is probable that redtop and meadow fescue could be added to the seeding mixture with profit where it is intended to cut the hay for home feeding and to follow several years of hay production by the pasturing of the fields before they are again plowed for corn. It is also certain that alsike clover may be profitably seeded with the grasses where the land is fairly well drained.

When clover is to be seeded the Clyde fine sand would be greatly benefited by the application of 1 to 2 tons per acre of finely ground limestone rock. This should be applied when the seeding to grass is made, usually with the seeding of the oat crop. It would also benefit both the oat crop and the grass seeding to apply finely ground raw phosphate rock at the rate of not less than 500 pounds per acre at the time of oat seeding. It has been demonstrated, also, that all crops are greatly benefited through the application of muriate of potash or kainit to such soils as the Clyde fine sand, especially where the content of organic matter in the surface soil is unusually high.

Proper liming and fertilization should greatly increase the yields of all of the general farm crops. Where possible, stable and yard manure should be applied to the corn ground.

Where the Clyde fine sand has been thoroughly well drained it has produced excellent crops of Irish potatoes. The average yields are estimated at 125 to 200 bushels per acre.

Rye is sometimes grown as a winter grain crop and serves well as a nurse crop for timothy and other grasses. It gives yields of grain which range from 10 to 20 bushels per acre.

The grasses usually seeded give yields of hay which range from three-fourths of a ton to 1½ tons per acre. In addition, large areas of marsh hay are annually cut, giving yields of approximately 1 ton per acre of rather coarse hay.

By far the greater part of this soil type is still used for natural pastures. Even in areas where drainage is only partially established and the intertilled crops and timothy may not be successfully grown, the wild grasses furnish an excellent grazing for a considerable portion of the year. Frequently the herds are grazed during the summer months and fed through the winter on marsh hay cut on adjacent areas and stacked on well-drained land. Such a field of marsh hay is shown in Plate I, figure 2. As a result of the large areas given to hay growing and pasturage there is a considerable live-stock industry conducted on the Clyde fine sand. This takes the form of the growing and fattening of beef cattle chiefly, although a small amount of dairying is also conducted near shipping points or local markets. Some hogs are fattened as an adjunct to the other forms of stock raising.

In other areas the Clyde fine sand is chiefly undrained and unoccupied for any other uses than pasturage and timber lot. Some small areas, near to city markets, have been drained and used for market gardening. The small fruits, particularly strawberries and raspberries, give good yields, while such crops as cabbage, onions, and celery may be grown to advantage where the organic matter is abundant in the surface soil and the depth to subsoil is not less than 12 to 18 inches. Table beets and turnips may also be grown. In the case of the vegetables the liming of the soil is requisite to the best results. This is particularly true of cabbage, onions, and beets. The latter furnish one of the best indicators among vegetable crops of the lime requirements of a soil. They are not grown to advantage upon any soil that is badly in need of lime and the yields are greatly increased by the abundant use of lime, either as ground limestone or marl or as quicklime, slaked, and applied some time before the seeding of a crop.

For the improvement of crop yields upon the Clyde fine sand better drainage is the first requisite. This should usually be followed by the liming of the land and the use of rock phosphate and muriate of potash or kainit. Wherever stable manures are available they should be applied to the intertilled crops in general farm practice and to all of the crops grown in market gardening or small-fruit production.

Many thousands of acres of the Clyde fine sand are utilized only for pasturage or the cutting of wild grasses. Most of the remaining area is used principally for a type of mixed general farming and stock growing. Only small areas are used for the more intensive forms of market gardening and small-fruit cultivation. Wherever markets for the products are available, the type is far better suited to the latter uses than to general farming.

The farm equipment of the Clyde fine sand is not materially different from that of other areas in the general farming section of the north-central States. It usually consists of a frame dwelling and of large or small barns, depending upon whether the chief interests of the farm center in cattle feeding or in the production of crops for sale. Large teams and heavy machinery are commonly employed in the tillage of the type.

CLYDE SANDY LOAM.

The Clyde sandy loam has been encountered in seven soil-survey areas, located in Indiana, Michigan, Pennsylvania, and Wisconsin. A total area of 127,296 acres has thus far been mapped. By far the largest proportion of this area has been encountered in the Saginaw Bay region in the southern part of Michigan. In fact the other areas of its occurrence are small and scattered.

The Clyde sandy loam to an average depth of from 8 to 12 inches is a dark-gray, brown, or almost black medium-textured sandy loam. The surface soil contains varying amounts of organic matter. In the lower-lying locations, in all depressions, and where drainage has been seriously obstructed there is a considerable accumulation of dark, mucky organic matter in the surface soil. Upon slopes and somewhat higher ridges, which frequently occur through the type, organic matter is present in less proportion and the surface soil becomes gray or light brown in color. In almost all cases the surface soil grades downward into a medium to fine sandy loam, which is usually darker just beneath the surface soil, but becomes gray or mottled gray, drab, or yellow at greater depths. At a depth of 3 feet or more the subsoil becomes a sticky, somewhat sandy clay.

The characteristic surface features of the Clyde sandy loam vary somewhat in the different localities where it has been found. This arises from the fact there have been some slight differences in the method of formation of the different areas of the type. In Greene County, Ind., the surface of the Clyde sandy loam is almost absolutely level and depressed below the upland areas in the portion of the county where it occurs. This arises from the fact that the Clyde sandy loam was probably formed as a somewhat sandy outwash when glacial waters were discharged down the present drainage ways of the Eel and White Rivers. For a time at least these waters were so ponded as to form a local glacial lake within which sandy outwash material was deposited. This was mingled with a considerable amount of organic matter from the vegetation that grew in the swampy areas which ultimately resulted. In the majority of the other areas where the Clyde sandy loam occurs the surface is gently undulating to somewhat ridged. In the Saginaw area, Michigan, the Clyde sandy loam represents areas of sandy glacial till or water-laid moraines where glacial material was deposited either through glacial outwash or at such low levels that shallow lake waters covered a considerable proportion of the distinctively glacial till. In such regions all of the lower-lying portions of the Clyde sandy loam were formed under water-logged, swampy conditions, and a large amount of organic matter was deposited under these circumstances.

The local drainage conditions for the Clyde sandy loam vary considerably. In northern Greene County, Ind., the area now occupied by this soil type constituted extensive marshes in the earlier days, and the dredging of large ditches was essential before any portion of the type could be reclaimed and used for agricultural purposes. In the Michigan areas where the Clyde sandy loam occurs extensively it was frequently the case that the higher lying and better drained portions of the type could be immediately used for agriculture without the installation of extensive drainage works. However, the lower lying and depressed portions of this soil have been considerably improved for agricultural occupation by the digging of short local ditches and occasionally through the installation of tile drains. In almost all cases the producing power of the soil is decidedly increased where tile underdrainage is practiced.

The Clyde sandy loam constitutes an excellent general farming soil, except where it still exists under swampy conditions. Corn is the principal crop grown upon this soil, and the yields range from 35 to 40 bushels per acre under average conditions, with yields attaining 80 bushels per acre under particularly favorable conditions of drainage and of long growing season. Oats are grown extensively, giving yields which range from 25 to 40 bushels per acre. Hay also gives excellent yields, ranging from 1 to $1\frac{1}{2}$ and sometimes as high as 2 tons per acre. Timothy alone is grown or timothy mixed with some of the clovers, usually the alsike or red varieties. In Michigan a considerable amount of clover is grown alone. The first cutting is saved for hay. Frequently the second cutting is allowed to mature seed and fair yields of clover seed are obtained. This is shown in Plate II, figure 1. These constitute the principal general farm crops produced upon the type.

The Clyde sandy loam where properly drained also constitutes an excellent soil for the production of Irish potatoes. The late or staple crops are principally grown, although near good markets an early market-garden crop is also produced. The yields range from 80 to 150 bushels per acre under normal conditions, but yields in excess of 200 bushels per acre are reported. Beans constitute another special crop extensively grown in the Michigan areas upon the Clyde sandy loam. Wherever the type is well drained, either naturally or artificially, good yields of beans are produced, ranging from 12 to 25 bushels per acre. Sugar beets are another crop which is grown to fair advantage upon the Clyde sandy loam. The yields range from 7 to 15 tons per acre, with an average of about 10 tons. Wheat, barley, and alfalfa are all grown to a small extent upon this soil type. Alfalfa may only be grown where artificial underdrainage has been installed. Otherwise the crop is likely to make a good stand for one or two years and then, when the tap root of the alfalfa reaches the poorly drained subsoil, difficulty is experienced in maintaining a stand.

The use of the Clyde sandy loam for the production of special crops has not been extensively undertaken, except in the case of beans, sugar beets, and potatoes. The type is also well adapted by its physical characteristics and its drainage conditions to the production of onions, cabbage, celery, beets, and turnips as market-garden crops. Locally tomatoes have also been grown to advantage, giving returns approximating $100 per acre. It is probable that, as the markets are developed and transportation facilities are extended large areas of the Clyde sandy loam, wherever it is found, will be utilized for special crop production in conjunction with general farming over the remainder of the type.

The better drained areas of the Clyde sandy loam in both the Alma area and the Saginaw areas in Michigan are particularly well suited to the growing of certain orchard fruits. For quinces, pears, and plums there is probably no better soil type in the areas mentioned. Many varieties of apples are fairly well suited to production upon the higher lying and naturally better drained portions of the type. Strawberries and the cane fruits may also be grown.

In all cases the Clyde sandy loam would be considerably benefited by the installation of additional tile underdrainage. In fact, imperfect drainage in the lower lying and depressed portions of the type constitutes the chief difficulty in producing large crop yields. It is a condition which must be remedied before the more intensive forms of agriculture, such as fruit growing and market gardening, may be successfully undertaken.

CLYDE STONY SANDY LOAM.

The Clyde stony sandy loam has only been encountered in the soil survey of the Saginaw area, Michigan, where this type covers an area of 8,000 acres.

The surface soil of the Clyde stony sandy loam is a dark-brown, medium-textured, gravelly sandy loam which has a depth ranging from 18 to 24 inches. This is underlain by a gray sandy loam or a mottled brown clay loam which contains a small amount of gravel. The most notable characteristic of the type is the presence of bowlders strewn in large numbers over the surface and occurring less abundantly in the subsoil. These bowlders are chiefly of granite and range in size from large rounded gravel to angular fragments 2 or 3 feet in diameter. It has been found necessary in bringing this soil under cultivation to remove the larger cobbles and bowlders, which are either piled in heaps in the field or else are removed and used in the construction of farm buildings and of fences around the fields. Wherever this has been done the surface soil is left in good tillable condition. A few areas of the type are almost entirely free from gravel and stone.

The Clyde stony sandy loam constitutes small, level, depressed areas occurring within the glacial moraine. The type is naturally fairly well drained, but the smaller areas receive seepage waters from the adjacent higher lands. There is frequently no natural drainage outlet or only a sluggish streamway, partly obstructed by rank vegetation.

The greater part of the soil type has been improved and brought under cultivation. It is used chiefly for general farming purposes. Corn yields from 25 to 40 bushels per acre, oats from 20 to 50 bushels, wheat from 15 to 20 bushels, and beans from 10 to 12 bushels per acre. Hay gives excellent yields, ranging from 1 to $1\frac{1}{2}$ tons per acre. Sugar beets are grown in a small way, giving yields of 7 to 15 tons per acre. Irish potatoes are also grown in small acreages. This type practically constitutes a phase of the Clyde sandy loam, which is distinguished from it through the considerable amount of stone and gravel occurring in both soil and subsoil.

CLYDE FINE SANDY LOAM.

The Clyde fine sandy loam has been encountered in 13 different soil-survey areas, located in 5 different States. The total extent of the type thus far mapped amounts to 147,456 acres. The larger part of this type occurs in the Saginaw area, Michigan, in Will County, Ill., and in some of the areas in New York, notably in Niagara and Jefferson Counties.

The surface soil of the Clyde fine sandy loam, to an average depth ranging from 9 to 12 inches, is a dark-gray, dark-brown, or almost black fine sand or fine sandy loam. The subsoil is a brown, gray, or yellow fine sandy loam extending to a depth of 2 feet or more, where it frequently overlies a brown or drab clay. Both the soil and subsoil are entirely free from gravel and stone.

In some of the larger areas where the Clyde fine sandy loam has been encountered, especially in Niagara County, N. Y., and the Saginaw area, Michigan, the surface of the type is slightly undulating to gently rolling in topography, and is billowy in general appearance from the occurrence of large numbers of low ridges and narrow depressions between them. There are many level areas even in connection with this billowy topography. The Clyde fine sandy loam is frequently found also in the form of long, low, narrow ridges along the margins of the areas where other soils of the Clyde series are extensively developed. It is probable that in the majority of instances these low ridge areas represent old beach lines or shallow water deposits where the wind has built up a considerable deposit. In some instances the Clyde fine sandy loam represents areas where streams have flowed into the old glacial lakes and developed low, nearly flat deltas. In all cases there has been more or less wind action in piling up the surface soil.

The low ridges which occur within the limits of the Clyde fine sandy loam are fairly well drained in their natural condition. The more level areas and the depressions between these ridges are frequently poorly drained. This is true also of the small areas of the Clyde fine sandy loam associated with the other soil types in upland areas. In nearly all instances the better drained portions of the Clyde fine sandy loam show a light-brown or yellow coloration of the surface soil, owing to the fact that not as much organic matter has been deposited in these locations as in the hollows and depressed areas which have not been as well drained.

The lower lying portions of the type are not only poorly drained because of their depressed position, but in many instances there is some seepage of water from adjacent, more elevated land areas. All of these depressed areas require artificial drainage to fit them for farming. In fact, in a number of the soil-survey areas where the type has been encountered it is still in timber or is used only for pasturage or some other extensive form of agricultural occupation. Yet a considerable proportion of the Clyde fine sandy loam is fairly well drained in its natural condition and can be occupied for the production of general farm crops or for special fruit and market-garden crops.

FIG. 1.—ONIONS GROWN ON CLYDE SAND, ALLEGAN COUNTY, MICH.

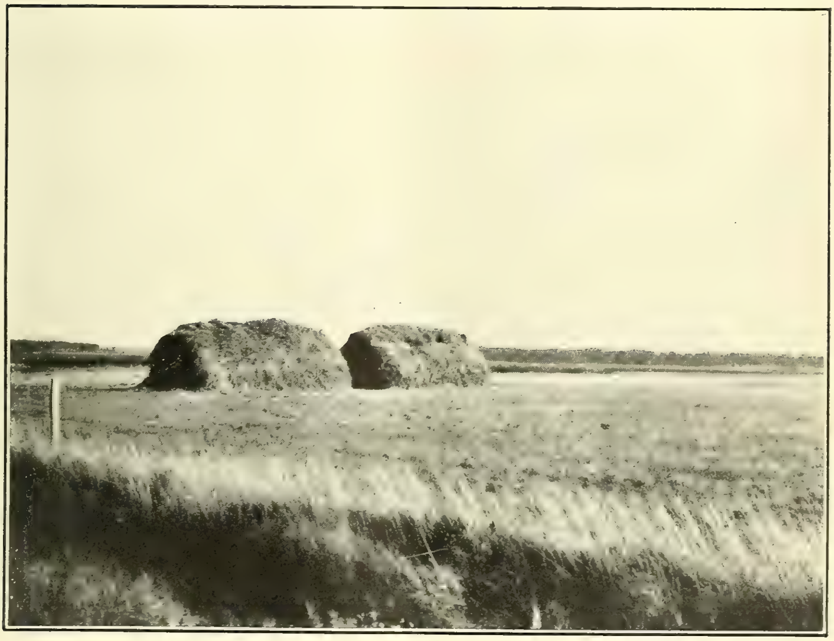

FIG. 2.—MARSH HAY CUT ON CLYDE FINE SAND ALONG THE KANKAKEE RIVER IN INDIANA.

FIG. 1.—HARVESTING SECOND-CROP CLOVER FOR SEED. CLYDE SANDY LOAM, NEAR SAGINAW, MICH.

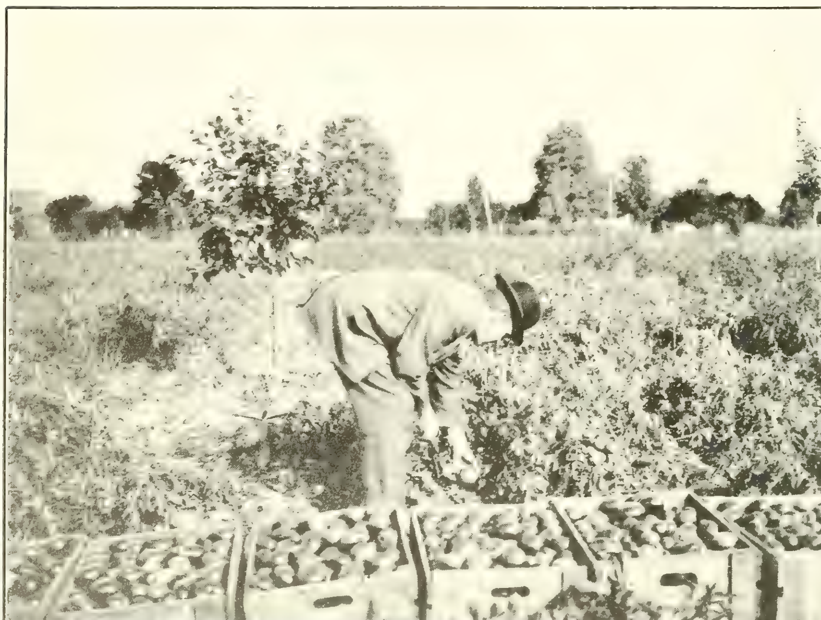

FIG. 2.—TOMATOES GROWN IN YOUNG PEAR ORCHARD ON CLYDE FINE SANDY LOAM, NIAGARA COUNTY, N. Y.

There is a considerable diversity in the uses to which the different portions of the Clyde fine sandy loam have been put in the production of crops. In almost all of the more western areas the general farm crops alone are produced. Thus in the Saginaw area, Michigan, where more than 39,000 acres of the type have been encountered, corn is one of the principal crops grown. The yields range from 20 to 40 bushels per acre. Oats constitute the principal small grain, giving yields of 30 to 50 bushels per acre. Beans are extensively grown, yielding from 10 to 25 bushels per acre, with an average approximating 15 bushels. Hay is also an important crop. Timothy and clover give yields of 1 to 1½ tons of hay per acre. Sugar beets yield 10 to 12 tons per acre. Chicory is also grown to some extent, the yields ranging from 7 to 12 tons per acre.

In Niagara County, N. Y., where an area of nearly 15,500 acres of the Clyde fine sandy loam has been encountered, the soil type is recognized as the best truck soil. This use is shown in Plate II, figure 2. It is extensively planted to cabbage, tomatoes, cucumbers, and potatoes as truck crops, while peas and beans are grown both as truck crops and for sale to the canning factories, which are numerous in this area. A considerable proportion of the type is thus utilized. In this area the general farm crops are also grown. Corn yields from 30 to 60 bushels per acre. A small amount of wheat is grown, giving fair average yields. Oats constitute the principal small-grain crop, with yields ranging from 25 to 50 bushels per acre. Navy beans and hay are also grown.

It is probable that wherever market facilities are afforded the Clyde fine sandy loam could best be developed as a special market-garden and small-fruit soil. It is well suited to the production of a considerable range of market-garden crops, while strawberries and cane fruits are grown to advantage. Wherever the type is well drained the orchard fruits may also be grown.

THE CLYDE LOAM.

The Clyde loam is the most extensive type which has thus far been mapped in the series. It has been encountered in 19 different soil-survey areas located in 4 different States, and an aggregate area of 565,676 acres has been mapped. It occurs to a limited extent in western New York, and in extensive areas in the Southern Peninsula of Michigan, in northern Indiana, and southern Wisconsin. It is probable that other large areas of the Clyde loam will be encountered in Michigan and adjoining portions of Indiana and Ohio as the soil-survey work progresses in those States.

The surface soil of the Clyde loam, to a depth in excess of 8 inches, is a moderately friable to rather heavy and compact loam, usually dark gray, brown, or black in color. Near the margins of the smaller areas of this type there is not infrequently a considerable mixture of sandy material, and in such instances the surface soil is more friable and of a lighter gray color. In all of the larger areas where it is developed and in the central portion of even the smaller areas it is almost jet black and contains such large amounts of organic matter as to be almost muck. The depth of the surface soil varies to a considerable degree, ranging from 8 or 10 inches near the margin of the type to a depth of 18 or even 24 inches in the central portion of large areas or in depressed locations occurring in any portion of the type. The subsoil of the Clyde loam is a gray, drab, or blue clay, sometimes mottled with yellow or brown iron stains. In almost all instances this subsoil is stiff, plastic, and impervious, but in certain instances where it is underlain at no great depth either by layers of peat or of marl the subsoil material may be somewhat jointed and less impervious than the average of the type. The Clyde loam in the majority of areas where it has been encountered is stone free, and even gravel is lacking. It is only in marginal areas or in locations where the surface covering of typical Clyde loam is somewhat thin that the stone or gravel of underlying glacial formations becomes evident. In Niagara County, N. Y., a phase of the type which constitutes only a thin covering over underlying glacial material is marked by the presence of stone and bowlders over its surface. This, however, is unusual.

The Clyde loam invariably occupies level or depressed areas which at some previous time have constituted the beds of glacial lakes or of large swamps. Such areas occur not only within the regions formerly occupied by extensions of Lakes Ontario, Erie, and Huron, but also in the beds of many smaller extinct glacial lakes which were ponded between the inequalities of the rolling to ridged glacial drift. In all instances the mineral matter from adjoining uplands was washed down and deposited in the form of fine or coarse sediments within these small or large lake beds, and as the water became shallower vegetation gained a foothold, giving rise to the incorporation of large amounts of mucky or peaty organic remains within the zone that now constitutes the surface soil.

The surface of the Clyde loam is almost invariably level, although in some areas low, rounded knolls and gentle swells within the general area of the ancient lake beds may also be covered by the same characteristic mucky swamp deposits. In all cases the area of the Clyde loam is distinctly depressed below the level of adjoining glaciated uplands and glacial moraines or below the level of the marginal glacial lake deposits.

The altitude of the surface of the Clyde loam varies considerably in the different areas where it has been encountered. Thus in

Niagara County, N. Y., the surface of the type ranges from 300 to 600 feet above sea level, while in the vicinity of Saginaw Bay, in the southern peninsula of Michigan, it lies from approximately 600 feet to about 750 feet above tide. Other separate areas in southern Michigan and northern Indiana have about the same altitude.

In all cases the Clyde loam is either poorly drained at the present time or was poorly drained prior to its occupation for agricultural purposes. In practically all areas where it occurs the Clyde loam constituted wooded swamps or grass-grown marshes in the days of pioneer occupation, and in the majority of instances other upland soils were first cleared and occupied. Later the obstructed natural drainage was improved by the straightening of streams and the opening of drainage ditches, and gradually increasing areas of this black mucky soil have been brought under cultivation. The Clyde loam in its undrained condition, wherever it is encountered, either constitutes swamp not occupied for any agricultural purpose or else forms pasture lands upon which cattle are grazed during the later months of the summer, or where, in the treeless areas, swamp grass is cut for hay. It has only been through the establishment of artificial drainage that this soil has been made available for agricultural use.

Owing to the swampy or semiswampy condition of the Clyde loam prior to drainage, the surface soil is frequently found to be in a puddled, compact state, sticky and impervious when wet and drying out to a clodded or cementlike surface when dry. These effects of poor drainage are emphasized where the finer-grained material is found in lower lying areas which have been under cultivation for only a short time. In such cases the soil proper is frequently stiff and sticky and clods badly when plowed. The continued cultivation of the type, however, and the long-continued operation of frost upon well-drained areas tends to correct this condition and to make the Clyde loam an extremely valuable soil for the production of the majority of the general farm crops suited to the temperate climate within which the type is most extensively developed.

In the case of the Clyde loam a larger acreage of the type is devoted to the production of grass for the cutting of hay than to any other crop. The type is not only well suited to produce large yields, but the management of the soil and of the general farming system in the areas where it occurs has brought about a crop rotation usually consisting of one year devoted to the production of a hoed crop, one or two years devoted to small grain growing, to be succeeded by two, three, or even five years of grass production in the course of the rotation. Because of the adoption of such long-term rotations, in which the land is frequently occupied during half of the entire period by the stand of grass, the acreage of this crop far exceeds that given either to the small grains or to the hoed crops. The yields of hay vary considerably in the different areas where the Clyde loam has been encountered. In general, in southern Michigan, northern Indiana, and western New York, the yields of hay range from 1¼ to 2 or even 2½ tons per acre. The average yields for the Clyde loam in these locations may be confidently stated at 1½ tons per acre, or greater, dependent somewhat upon seasonal variations in the rainfall. Mixed timothy and clover constitute the principal acreage, although upon the better drained areas clover, seeded alone, is an important crop, both for the production of hay and, in central Michigan, for the production of seed. The alsike clover and the medium red clover are used to a considerable extent both in mixed and pure seeding. It has been found that the alsike clover will make an excellent growth even where drainage has not been thoroughly established, while the medium red clover is somewhat more exacting and requires good to perfect drainage to produce its maximum yields.

Among the small grains wheat is the most important, although the acreage devoted to this crop in the more eastern States is decreasing and the yields are not especially high. They range from 10 or 12 bushels per acre to 20 bushels or more. The average is not much more than 15 bushels per acre. This is, however, in excess of the yields secured upon many of the upland soils in the same general region. Oats are even better suited to the Clyde loam than either winter or spring wheat, and the yields are high in the different areas where the crop is grown. In Michigan the yields range from 35 to 60 bushels per acre, while the general average through a long period of time may be stated at 40 bushels per acre, or somewhat greater. Consequently the oat crop is, to a considerable extent, displacing wheat as the small grain crop. Aside from a tendency toward excessive growth of straw, the Clyde loam constitutes an almost ideal soil for oat production.

In all of the areas where the Clyde loam is developed, corn constitutes its most extensive intertilled crop. The yields are fair to good, ranging from 25 to 45 bushels per acre with a general average of about 35 bushels. Its use for corn growing is shown in Plate III, figure 1.

Many thousands of acres of sugar beets are annually grown upon the Clyde loam in the southern peninsula of Michigan, and there is a strong tendency to increase this acreage in all localities where an adequate supply of labor for the care of the crop can be obtained. The average yield ranges from 7 to 10 tons per acre with exceptional yields as high as 15 to 18 tons.

Beans are grown to some extent as an intertilled crop, preceding either wheat or oats, in both Michigan and Indiana. The yields are good, ranging from 18 to 25 bushels per acre, with an average yield of 20 bushels. Rye, barley, and buckwheat are also produced to a small extent, giving fair yields.

In some localities there are also small acreages planted to cabbage or celery, the former crop yielding from 8 to 15 tons per acre, with an average of about 12 tons. The quality of the cabbage produced upon the Clyde loam is reported to be excellent. Only a small area of either onions, peppermint, or strawberries, is now produced upon the type, although it is well suited to the growing of each of these crops when economic conditions are favorable.

The farm equipment upon the Clyde loam does not differ materially from the equipment upon other soils in the same general regions. It may be said that larger teams and heavier tools are required for the perfect tillage of this soil than upon any others of similar or lighter texture. The somewhat plastic and dense character of both the surface soil and the subsoil requires deep plowing and thorough subsequent tillage in order to maintain the surface soil in mellow, friable condition. Since the Clyde loam is practically stone free in the majority of areas the use of disk plows and disk harrows is easily possible. The employment of such machinery should obviate the tendency toward the forming of a plow sole or "hardpan" at the normal depth of plowing, a difficulty sometimes encountered in the use of the ordinary turning plow.

The dominance of grass, oats, and corn as the principal crops upon the Clyde loam led to the introduction of dairying as an important adjunct to crop production in the early days of the occupation of this type. The excellent pasturage afforded, the heavy cutting of hay, the large yields of oats, and the satisfactory yield of corn, all led the pioneer farmers, who were usually predisposed to dairying from their experiences in their former locations, to adopt this form of crop disposal. The dairy farms upon the Clyde loam, particularly in Michigan and Indiana, are apparently among the most profitable and best maintained farms in the region. Upon these dairy farms a considerable amount of stable manure is annually returned to the fields and crop yields are maintained at or above the average for the general locality. The production of wheat has largely been superseded by the production of corn and oats upon the majority of dairy farms. The building equipment is somewhat more elaborate than upon the general-crop farms found upon the Clyde loam, because of the necessity for housing the stock and the roughage for feeding purposes.

CLYDE SILT LOAM.

Seven areas of the Clyde silt loam have been encountered in the course of the soil survey work. Four of these are in southern and central Wisconsin, and they comprise by far the largest acreage which has yet been found. The total area of this type thus far encountered amounts to 122,368 acres.

The surface soil of the Clyde silt loam, to an average depth of 10 or 12 inches, consists of a dark brown or almost black silt loam. It contains a large quantity of organic matter and is rarely gritty or friable. The subsoil is a dark gray or drab silty clay loam which is decidedly compact and sticky. The subsoil occasionally contains some fine gravel and pockets or lenses of sand. In some areas, particularly in the Saginaw area, Michigan, bowlders are scattered over the surface of the higher lying portion of the type. In general it is nearly stone free.

Usually the surface of the Clyde silt loam is nearly level or gently sloping. It is almost always depressed below the level of surrounding upland soil types, although in one or two areas where the Clyde silt loam occupies upland positions its surface is gently rolling. In almost all cases the Clyde silt loam is very poorly drained in its natural condition. This arises from the surface topography of the type and from the fact that it occurs in basins and along stream courses where the natural drainage has not become established. In nearly all cases the drainage of this soil through open ditches and tile underdrainage is necessary before agricultural occupation can take the more intensive forms.

A very small proportion of the total area of the Clyde silt loam has been brought under cultivation. In general the areas are either timbered or occupied by marsh grasses. In the Saginaw area, Michigan, where the type is found upon the gently rolling uplands, practically the entire area has been brought under cultivation for the production of farm crops. Corn, oats, and hay are the chief crops grown upon it in the area, while a limited acreage is devoted to the production of sugar beets. Where the drainage is adequate the crop yields are fair to good. In other localities only small tracts of the Clyde silt loam have been drained and in southern Wisconsin, corn, timothy, alsike clover, oats, peas, and sugar beets constitute the principal crops. Corn gives excellent yields where drainage is good. It has been found in seeding to mixed grasses, that alsike clover is better suited to this soil than red clover, especially until drainage has been thoroughly established.

The Clyde silt loam is naturally a strong productive soil and adequate drainage is the chief need for its more intensive occupation. In many instances a single line of tile would serve to drain considerable areas of this soil while in the larger tracts it would be necessary to install open ditches to serve as main outlets into which lateral tile drains could be led.

CLYDE SILTY CLAY LOAM.

During the progress of soil survey work the Clyde silty clay loam has been mapped in 11 different areas located in New York, Ohio, Indiana, Illinois, and Wisconsin. The total area thus far mapped amounts to 401,984 acres. Additional areas of considerable extent will undoubtedly be encountered in these regions during the progress of soil survey work.

The surface soil of the Clyde silty clay loam to an average depth of 10 inches is a dark-brown to black sticky, silty clay loam. When wet it is a dull black in color and decidedly plastic and claylike. Upon becoming partially dried it assumes a lighter brown or gray or grayish-brown color and usually develops a granulated or crumb-like structure. Nearer the margins of the areas of this type the color is usually a lighter brown, the surface soil may have a depth of only 5 or 6 inches, and the admixture of coarser grained material sometimes renders it rather more loamy than the typical area.

The subsoil to a depth ranging from 15 to 20 inches is most frequently a dark brown or almost black silty clay loam which becomes gradually lighter colored with depth and at about 2 feet grades into a drab or dark-blue sticky clay loam. This is most frequently underlain by a yellow or mottled yellow and gray plastic clay loam.

There is a considerable variation in the depth of the brown or black material overlying the deeper subsoil. In all of the smaller areas of the type, comprising a few acres in a place, the darker surface material has a depth of about 1 foot. In the larger areas, comprising tracts of several square miles in extent, the dark colored, surface material usually has a total depth of 18 inches to 2 feet. In all of these there is a tendency toward a thickening of the dark surface material toward the central portion of the different areas of the Clyde silty clay loam.

Neither stone nor gravel are commonly found in either the soil or subsoil of this type. In some instances small amounts of gravel may be found around the margins of the different areas or underlying the deeper subsoil.

The Clyde silty clay loam is most extensively developed in basin-like depressions associated with the upland glacial soils throughout western Ohio and central Indiana. It occurs in the hollows and depressions in the rolling area occupied chiefly by the Miami silt loam and the Miami clay loam. It is also found in small ponded or swampy areas associated with the moraines and glacial uplands in New York and Wisconsin. Considerable areas are also found through the Great Lake region, where ancient glacial lakes have become wholly or partially drained. In all cases the areas of the Clyde silty clay loam are marked by nearly level or only slightly sloping topography. In practically all cases these different areas represent either lakes and ponds or extensive swamps which existed before artificial drainage was supplied. In its natural condition the Clyde silty clay loam supported a heavy growth of deciduous water-loving trees, including several varieties of oak and ash, elm, and silver maple. Treeless areas were covered with a rank growth of sedges and swamp grasses. In the early settlement of the country these swampy areas were left undrained, and it is only within more recent times that large areas of the Clyde silty clay loam have been redeemed for agricultural uses through the installation of expensive open drainage ditches and the laying of tile underdrains. In some of the smaller areas the cutting of a single drainage ditch has frequently been adequate to drain the type, while larger areas have been brought under cultivation through the extensive community ditches into which individual farms and fields have been drained by means of tile. At the present time nearly all of the larger areas and many of the smaller tracts have been thus improved, and probably 75 per cent of the total area of the type is now used for the production of some crop.

The Clyde silty clay loam consists of poorly drained areas in the glacial till upland, of swampy tracts along some of the smaller streams, and of areas of previously swampy land in the basins of extinct glacial lakes. The surface material to a depth of 2 feet or more usually consists of a mingling of silty material washed in from the surrounding uplands and of a large amount of partially decayed organic matter contributed by the marsh vegetation which flourished under previous conditions.

The Clyde silty clay loam requires rather careful management to secure the best crop results. If it is plowed and harrowed when either too moist or too dry it is liable to become baked or clodded, with a corresponding decrease in crop production. When it is plowed in the proper condition of moisture the surface soil crumbles into a granular loamy mass capable of producing excellent crops. It is upon thoroughly drained areas that the best results are obtained, and drainage is the most fundamental form of improvement for this type.

In practically all of the areas where the Clyde silty clay loam has been adequately drained corn constitutes the chief crop. It is usually planted for two or more years in succession before being followed by a small grain crop. In some instances it has been grown for 10 or 15 years without serious diminution in yield. Corn produces from 40 to 80 bushels per acre, with a general average in excess of 45 bushels per acre. Both the yellow and white dent varieties are grown. A considerable acreage of corn is grown for cutting into the silo, giving yields of 12 to 15 tons per acre. This use of the corn

FIG. 1.—HARVESTING A HEAVY CORN CROP ON CLYDE LOAM, NEAR SAGINAW, MICH.

FIG. 2.—CABBAGE ON CLYDE CLAY LOAM, NEAR RACINE, WIS.

FIG. 1.—A YIELD OF MORE THAN 60 BUSHELS OF CORN PER ACRE ON CLYDE CLAY IN NORTHERN INDIANA.

FIG. 2.—PASTURING HOGS ON BLUEGRASS AND CLOVER TURF. TILE DRAINED CLYDE CLAY IN NORTHEASTERN INDIANA.

crop prevails in the more northern latitudes where dairying is extensively conducted.

Oats are the important small-grain crop upon the Clyde silty clay loam. This crop usually follows corn in the rotation and under conditions of favorable season gives yields ranging from 40 to 60 bushels per acre. There is a tendency toward the lodging of the grain, especially upon areas where drainage is not complete. The yield is thus somewhat reduced.

Wheat is only grown to a limited extent on the Clyde silty clay loam and with extremely variable yields, which range from 14 to 25 bushels per acre.

The Clyde silty clay loam is an excellent soil for grass production, and large areas are seeded to mixed timothy and clover or to clover alone. The seeding is either made in the spring with the oat crop or the timothy is sown in the fall with the wheat and the clover is harrowed in during the succeeding spring. Yields of hay range from $1\frac{1}{2}$ to $2\frac{1}{2}$ tons per acre, probably averaging about $1\frac{3}{4}$ tons. Some areas of the Clyde silty clay loam where drainage has only been partially established support a heavy growth of marsh grasses, which are either cut for hay or are utilized as pasturage. The yields of marsh hay range from 1 to 2 tons per acre.

Special crops are grown only to a limited extent on the Clyde silty clay loam. In some areas in Wisconsin sugar beets are grown, giving yields of 12 to 18 tons per acre. In that State, also, both cabbage and onions are produced upon this soil, the former giving yields of 12 to 15 tons and the latter 300 to 500 bushels per acre. Irish potatoes are grown to a limited extent, producing yields of 100 to 300 bushels per acre. The potatoes are usually not of first quality.

The most common rotation upon the Clyde silty clay loam consists of corn planted for two or more years in succession and followed by oats. Seeding to mixed grass and clover is made with the oat crop. Hay is cut for one or two years and the lands may be pastured for an additional year. The rotation then returns to corn. The value of the Clyde silty clay loam for corn production is so generally recognized that there is a constant tendency to plant corn as often as is possible. In consequence the greatest acreage in grain is usually devoted to this crop. It is probably only exceeded, if at all, by the acreage given to hay.

Very little has been done in the line of fertilizing the Clyde silty clay loam, the majority of farmers depending upon the inherent fertility of the soil for the maintenance of crop yields. Stable manure is used probably more extensively than any other material, being applied to the second or third crop of corn. In some localities a small amount of commercial fertilizer is applied with the small-grain crop.

The Clyde silty clay loam requires the use of heavy work animals and of improved farm machinery for its proper preparation and tillage. These are extensively employed throughout the region where it occurs.

Except where the Clyde silty clay loam is found in tracts covering several square miles, farm buildings are usually located upon some other soil type, most frequently upon some upland soil whose better drainage renders it more suitable for such purposes.

The crops grown upon the Clyde silty clay loam are to a considerable degree fed upon the farm to dairy cows, beef cattle, and hogs. In the more southern localities a part of the corn and oat crop may be sold from the farm. The type in general constitutes an excellent general purpose farming soil used to a limited degree for the growing of special crops and in some localities developed as the basis for the fattening of stock or the dairy industry.

CLYDE CLAY LOAM.

The Clyde clay loam has only been mapped in five areas, in Michigan, New York, Illinois, and Wisconsin, the principal area lying in Racine County, in the last-named State. The total area thus far encountered amounts to 19,392 acres.

The surface soil of the Clyde clay loam to an average depth of 8 or 10 inches is a dark-brown or black loam. It rests upon a yellow or drab colored clay subsoil which is often streaked with iron stains. Very little coarse material is found in either the surface soil or the subsoil.

The Clyde clay loam is confined to level areas somewhat depressed below the level of the country in which it occurs. It occupies either small scattered basinlike areas in the upland or somewhat larger areas in old glacial lake plains. In consequence of its position and of the stiff impervious character of the subsoil, it is almost always poorly drained in its natural condition. In fact, the agricultural occupation of the type is dependent upon the installation of artificial drainage.

Comparatively few of the Clyde clay loam areas are under cultivation, and where it has not been artificially drained the type is either timbered or is used for the cutting of wild hay and for pasture. It is only in the vicinity of Racine, Wis., that any large area of this soil has been occupied for the production of farm crops. In this region the installation of drainage has permitted the production of corn, which gives yields of 40 to 60 bushels per acre; of oats, with yields ranging from 30 to 50 bushels; and of hay, principally timothy, giving yields of 1 to 2 tons per acre.

In the immediate vicinity of Racine, the type is quite extensively devoted to the cultivation of cabbage and onions. Cabbage produces from 10 to 15 tons per acre, onions 400 to 700 bushels per acre, while potatoes, which are also grown to a small extent, give yields from 150 to 250 bushels per acre. An excellent field of cabbage, grown on the Clyde clay loam, is shown in Plate III, figure 2.

Elsewhere the Clyde clay loam, where appearing in small areas scattered through other soil types, is either tilled to the general farm crops or, where occurring in larger areas, is utilized mainly for pastures.

CLYDE CLAY.

Next to the Clyde loam the Clyde clay is the most extensively developed soil type of the series. It has been encountered in eight different soil-survey areas, located in New York, Ohio, Indiana, Illinois, and Michigan. A total area of 319,424 acres has been mapped, of which considerably more than one-half is found in the soil survey of the Toledo area, Ohio, where 165,056 acres occur. It is probable that other large areas will be encountered in the Maumee basin and in the area of glacial Lake Saginaw, not yet covered by soil surveys.

The surface soil of the Clyde clay, wherever it has been encountered, is characteristically a dark-gray, drab, or nearly black clay loam. It is well filled with organic matter to a depth of 8 or 10 inches, and this renders the surface soil considerably more friable and easily worked than would ordinarily be the case with material of such fine texture. There is usually a strong tendency toward granulation of the surface soil, due to the high amount of organic matter contained and to the fact that both the soil and subsoil are somewhat calcareous. The subsoil to a depth in excess of 36 inches is a lighter gray, drab, or mottled yellow and gray clay. It is dense and sticky when wet, but becomes intersected with numerous joints and crevices when properly drained and exposed to the action of the atmosphere. It frequently contains gravel, the quantity varying from a few scattered pebbles to a considerable percentage of the soil mass. Neither the soil nor the subsoil contain any considerable number of stones of larger size. In other cases it is free from any trace of gravel and stone and consists of laminated or massive lake clay. In the former instance it is probable that the type constitutes merely a thin surface veneering of glacial lake or swamp material over the underlying till or water-laid glacial deposits. In the latter it is a true glacial-lake deposit.

In all cases the surface soil gives the distinctive evidences, through the color and the accumulation of organic matter, of the swampy condition under which it was formed.

It is a common characteristic of the Clyde clay, possibly more general than with other soils of the series, that the subsoil contains a high percentage of carbonate of lime. Analyses of numerous samples have shown the lime carbonate content to range from 1 or 2 per cent to as high as 20 or 25 per cent. This arises from the close association of the largest areas of the type with areas where the local limestone was first reworked into the glacial till and later redeposited as a part of the glacial lake sediments which constitute such a large proportion of the total area of the type.

In all areas where it occurs the Clyde clay occupies level or slightly saucer-shaped depressions which are usually below the level not only of other upland soils but even below that of other members of the Clyde series occurring in the same area. In fact, the Clyde clay represents the quiet-water deposition of the ancient glacial lakes, and it was formed in the central portions of the basins of the larger lakes and in depressions in other glacial lake sediments. In such locations the deposition of mineral matter was not usually as great as nearer shore lines or stream deltas, and the deposits were finer grained than in the case of the materials giving the other members of the series.

The surface of the Clyde clay is almost universally flat or but slightly inclined, and there is abundant evidence that the areas of this type constituted shallow lakes or at most swamps until about the time of the pioneer occupation of the general region. The presence of numerous fresh-water shells, the high organic matter content of the surface soil, and many historical accounts of the original aspect of the country all bear out this conception of the immediate origin of the Clyde clay.

Not until artificial drainage was undertaken either by individuals or by county or State authorities was the greater part of the total area of the Clyde clay susceptible of agricultural occupation. It has only been after the opening of large main ditches, along the boundaries of land sections or along natural drainage ways through which farm drainage might find an outlet, that the land has been brought under even the more extensive forms of cultivation, and the production of intertilled crops has frequently become profitable only after the installation of tile drainage. It is certain that many thousands of acres of this soil type would be very greatly benefited by the extension of tile drainage. The value of this form of improvement has been abundantly demonstrated by numerous cases where the value of the land has been quadrupled through the laying of tile. Usually the increased value of the land has more than paid for the expenditure within 5 to 10 years from the installation of the drains, while it has even been the case that the increased crop production for the same period of time has more than paid the total cost of drainage. It is certain that the crop adaptations of the type are greatly broadened by drainage and that the yields obtained are greatly increased. The certainty of obtaining a crop under all conditions of precipitation is another advantage to be derived from underdrainage.

Wherever the Clyde clay has been drained sufficiently to render it suitable for corn cultivation that crop exceeds all others in acreage and value. In fact it is one of the best corn soils of the Central States. This is well shown in Plate IV, figure 1. Good yields are only obtained from drained lands, and where drainage has not been effected there is very little corn grown. In northwestern Ohio the value of the Clyde clay for corn production is so well appreciated that more than one-third of the total improved acreage of this soil is planted to corn annually. The yields for counties consisting largely of the Clyde clay range from 38 to 41.5 bushels per acre. It may be said that the average yield of the type in this region is probably in excess of 45 bushels per acre, while the crops grown upon the best drained land frequently exceed 60 bushels per acre. The large-growing dent varieties, requiring a long growing season, are commonly planted. The corn is produced chiefly for the grain, although a minor use is made of silage corn for the feeding of beef cattle and, to a more limited extent, in the feeding of dairy cows. Yields of silage range from 12 to 15 tons per acre.

In other localities it is not so easy to select the figures representing the yields of the Clyde clay, since other soil types dominate it in area and obscure its relative importance. Yet it is producing from 25 to 50 bushels of corn per acre in Niagara County, N. Y., depending upon the local drainage conditions, and even higher yields in Allen County, Ind. In the Saginaw area, Michigan, it has not yet become sufficiently well drained to constitute a first-class corn soil under the somewhat cooler climatic conditions existing there. With tile underdrainage it should be well suited to this crop.

In the more southern areas, where the Clyde clay is an important soil, oats are the crop of next importance to corn in point of acreage. Oats usually occupy from one-fifth to one-fourth of the total improved area of the type. The yields are not relatively so heavy as in the case of corn, but they range from 30 to 50 bushels per acre, with a general average of 40 bushels. There is a tendency toward the lodging of the straw when oats are grown upon this moist soil, so well filled with organic matter, and the yields of harvested grain are as high upon portions of the type which are marked by the gray surface soils as upon the generally more productive, darker-colored phase. In fact, oats are said to yield better crops of grain after the land has been cropped for some years to corn. Wherever the Clyde clay is fairly well drained it is uniformly a good oat-growing soil.

Hay and pasture grasses constitute the chief remaining crop grown upon the Clyde clay. Usually the area devoted to grass growing in the Central States is decidedly subordinate to that given to corn and oats. In New York State grass constitutes the chief crop grown upon the Clyde clay. This arises from the fact that little of the type has been sufficiently drained to make it a suitable soil for the production of intertilled crops. The same is partly true of the Saginaw area, Michigan. In all areas timothy, seeded alone, comprises the largest grass acreage. The Clyde clay is almost an ideal soil for timothy production. It is moist, well supplied with organic matter, and mildly calcareous. Unless the yields are decreased through poor drainage the production frequently exceeds $1\frac{3}{4}$ tons per acre at a single cutting. Total yields of $2\frac{1}{2}$ tons per acre at two cuttings are not infrequently obtained. In many instances the second crop is cut and thrashed for the seed. Mixed timothy and clover also occupy large areas on the type. Both the red and alsike clovers are seeded with the timothy where the hay is grown for feeding rather than for the city market. Clover is grown alone upon this soil, but to a limited extent. The yields of mixed hay range from $1\frac{1}{2}$ tons to $2\frac{1}{2}$ tons per acre. Clover yields as high as 2 tons with an average of $1\frac{1}{2}$ tons per acre.

Wherever the Clyde clay has become well drained the Kentucky bluegrass spreads naturally over the fields not kept in constant cultivation. It forms a thick mat along the roadsides and invades fields which have been seeded to other grasses for any length of time. Wherever it is permitted to remain it forms an excellent pasturage and, if the land were not usually much more valuable for growing the tilled crops or other grasses, it would constitute one of the best sources of pasturage in the Central States. The use of such a field for pasturing hogs is shown in Plate IV, figure 2.

Where tile drainage has been completely installed and the land fully drained to a depth of 3 feet or more, alfalfa succeeds very well upon the Clyde clay. Drainage is a fundamental essential to success with this crop, but otherwise the soil is in excellent condition for alfalfa seeding. It is productive, well supplied with organic matter, and so calcareous that liming is usually unnecessary. Even the inoculation with the proper bacteria is sometimes naturally secured through the rather general growth of sweet clover or Melilotus throughout the area occupied by the better-drained portions of the type. Upon well-drained fields of alfalfa south of Toledo, Ohio, $3\frac{1}{2}$ to 4 tons of hay per acre are obtained in three or four cuttings each year. Such a field is shown in Plate V, figure 1. The stand of alfalfa usually lasts for four or five years. It is then advisable to plow the land for corn, as Kentucky bluegrass will usually invade the fields to such an extent that tillage for a year and then reseeding to alfalfa is more profitable than continuing the harvesting of the mixed hay.

Winter wheat is a minor crop upon the Clyde clay, although it was formerly extensively grown. The yields are still above the average for the wheat-growing States, but the increased value of the land has rendered the production even of fairly large crops no longer profitable. Yields of wheat range from 15 to 25 bushels per acre on the Clyde clay.

Within recent years sugar beets have come to be grown to quite an extent upon the Clyde clay. The tonnage secured is good, ranging from 10 to 12 tons per acre of beets of rather high sugar content. The beets are grown to best advantage where tile drainage has been established. They may not be grown where drainage has not been perfected, at least by open ditches. A very uneven stand is obtained where drainage is neglected. It is probable that the Clyde clay is second in value only to the Clyde loam as an eastern sugar-beet soil. The acreage upon this type should be extended as rapidly as factory facilities are provided.

Potatoes are grown on this type only to a very limited extent and chiefly for home use. Wherever another more friable soil is available it should be used for Irish potatoes in preference. Yet yields of 100 bushels or more per acre may be obtained upon well-drained land. The tubers are likely to be rather dense and to cook to a dark color.

It is apparent from the crop adaptations of the Clyde clay that it is a soil whose most productive crops are especially well suited to the fattening of beef cattle, the feeding of dairy cows, and the growing and fattening of hogs. This type of farming is being gradually extended over the different areas of the Clyde clay, although the present dominant form is usually that of producing corn, other grains, and hay for sale. The fact that corn, mixed grasses, bluegrass for pasture, and even alfalfa, may be grown to excellent advantage upon this soil marks it as destined to become more and more a stockgrowing and dairying type.

In all cases where the Clyde clay has been drained and used for tillage forms of agriculture the equipment of farm buildings is that of a prosperous general farming community. The dwellings and outbuildings are most commonly frame structures or the house is of brick. The teams used are among the heaviest and best of the Central States. The implements and machinery used are commonly of improved sorts well suited to the management of a stiff and refractory soil. Yet there are portions of the type where drainage is just becoming established where the old log house and barn still persist and where the improvements have not yet attained to the excellent condition of the longer occupied areas. There are still thousands of acres of this excellent soil that await drainage and occupation.

CROP USES AND ADAPTATIONS.

A general review of the crop adaptations of the different soils of the Clyde series may be presented in tabular form. The materials from which this tabulation is compiled comprise the results obtained in 26 different soil surveys, located in 6 different States, and covering an aggregate area of more than a million and a quarter acres of the different soils. Because of the widespread distribution of the areas and of the very different conditions of drainage and utilization which are prevalent in these different areas, the tabulation is decidedly generalized, and may be taken to comprehend the chief crop adaptations of each soil type, with local differences of climate and of drainage, either natural or artificial, eliminated, or at least subordinated to a rank of minor importance. The instances considered also comprehend considerable variations in market and transportation facilities, so that the general summary possesses the widest possible application.

This table is to be understood to refer only to the agricultural conditions as they exist at present in the region chiefly occupied by the soils of this series. The table makes no prediction as to ultimate crop adaptations when the soils of this series have become more generally and more thoroughly drained, or when a larger number of different crops has been tried out and the unsuited crops discarded for those which give the best economic results.

Tabular summary of the crop adaptations of soils of the Clyde series.

Soil type.	Specific adaptations.		
	Of prime importance.	Of moderate importance.	May be grown.
Sand group:			
Clyde sand		Rye, beans, early Irish potatoes, clover.	Corn, oats, mixed hay.
Clyde gravelly sand.		Rye, buckwheat, clover	Corn, oats.
Clyde fine sand		Rye, Irish potatoes, clover.	Corn, mixed hay.
Sandy loam group:			
Clyde sandy loam		Corn, oats, timothy and clover, beans.	Sugar beets, tomatoes, potatoes, alfalfa.
Clyde stony sandy loam.		Corn, oats, timothy and clover, beans.	Sugar beets, wheat, oats, apples.
Clyde fine sandy loam.	Corn, oats, hay, beans.	Wheat, sugar beets	Cabbage, onions, chicory.
Loam group:			
Clyde loam	Corn, oats, hay, sugar beets, beans.	Wheat, rye, barley, buckwheat.	Cabbage, alfalfa, apples, pears, quinces.
Clyde silt loam	Corn, oats, hay, sugar beets.	Pasturage, in poorly drained areas.	
Clay group:			
Clyde silty clay loam.	Corn, hay, sugar beets.	Oats, barley, cabbage	Late potatoes, cauliflower.
Clyde clay loam	Corn, oats, hay, bluegrass pasture.	Cabbage, onions	Late potatoes (small area cleared and drained).
Clyde clay	Corn, hay, sugar beets, bluegrass pasture.	Wheat, oats	Late potatoes, alfalfa on tile-drained land.

FIG. 1.—THIRD CUTTING OF ALFALFA IN ONE SEASON. TILE DRAINED CLYDE CLAY, NEAR GENOA, OHIO.

FIG. 2.—PULLING SUGAR BEETS, NEAR OWOSSO, MICH.

FIG. 1.—TOPPING BEETS. CLYDE LOAM, NEAR ST. JOHNS, MICH.

Note piles of tops available for stock feeding.

FIG. 2.—LOADING BEETS TO HAUL TO SHIPPING STATION, NEAR GENOA, OHIO.

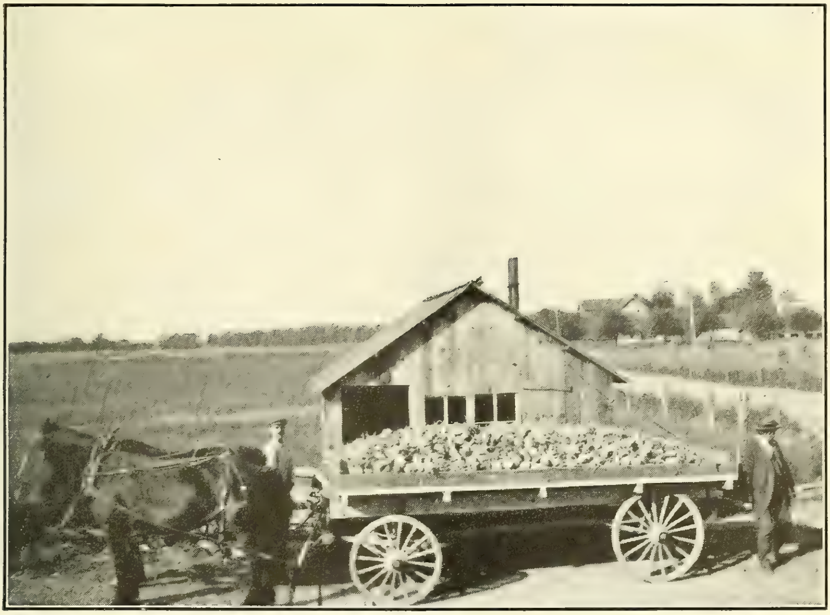

FIG. 1.—WEIGHING IN AND SAMPLING BEETS PRIOR TO SHIPMENT TO THE SUGAR FACTORY, NEAR OWOSSO, MICH.

FIG. 2.—SHIPPING SUGAR BEETS AND CABBAGE, NEAR RACINE, WIS.

FIG. 1.—LOADING CARS BY MEANS OF CHUTES. A LABOR-SAVING DEVICE IN SHIPPING BEETS.

FIG. 2.—A DAY'S LOADING IN THE MICHIGAN SUGAR-BEET TERRITORY.

SUGAR BEETS.

The climatic zone within which sugar beets may be advantageously grown under humid conditions crosses the northern part of the United States, including practically all of the Great Lakes region. Within this section of the country there is a wide diversity in soils and upon many of these different soils the cultivation of the sugar beet has been attempted at one time or another during the last 20 years. As a result of the gradual elimination of soils not well suited to the crop the industry in the north-central States has become somewhat concentrated within areas which are dominated by the soils of the Clyde series. The first intimation of this was obtained by the Bureau of Soils in the summer of 1904, when soil surveys were made in several areas through the southern peninsula of Michigan for the purpose of determining the kinds of soil best suited to the growing of sugar beets upon a commercial scale.

While sugar beets may be grown upon quite a variety of soils[1] it soon became evident from a field study of the soils of the beet-producing region that a typical beet soil must be one which is in such physical condition as to maintain a considerable supply of soil moisture during the growing season without becoming waterlogged; that the best sugar-beet soils were also sufficiently friable to enable the beet roots to penetrate to a considerable depth; that the most successful crops were grown upon soils well supplied with organic matter; and that the tonnage of the crop was generally greatest upon soils which were at least mildly calcareous.

The heavier soils of the Clyde series meet all of these requirements, and it became evident that the sugar content and index of purity of the beets grown upon the different soils of the Clyde series always compared favorably with those of beets grown upon any other soils, while these factors of quality were usually best in beets grown upon the Clyde loam or some very similar soil.

A consideration of the acreage and yield of sugar beets in the lake-region States will serve to show how closely the growing of sugar beets is associated with the soils of the Clyde series.

The State of Michigan reports considerably more than one-fifth of all the acreage of sugar beets grown in the United States in 1909.[2] Only the States of Colorado and California exceed the Michigan acreage, and the latter State only by a few acres. Wisconsin is the only other Eastern State which produces any large acreage, although portions of Ohio and Indiana show small plantings.

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[1] See Farmers' Bulletin No. 568, Sugar-beet Growing under Humid Conditions, for a complete discussion of sugar-beet growing.

[2] Census of the United States, 1910.

It is more than a mere coincidence that the counties in Michigan which report over 1,000 acres of sugar beets all contain large areas of the soils of the Clyde series, while all but one of such counties lie in or adjacent to the glacial lake basins where the soils of the series dominate. The six leading Michigan counties in sugar-beet acreage are Bay, Gratiot, Huron, Saginaw, Shiawassee, and Tuscola. Reference to the map, figure 1, will show that all of these counties lie in or adjacent to the area of the old glacial Lake Saginaw. These six counties contain two-thirds of the total acreage of sugar beets grown in the State, and they yield over seven-tenths of the total tonnage produced. A field inspection of the location of the beet acreages in such counties as Shiawassee, where only a portion of the total area lies in the lake basins, only emphasizes the close association of beet production with the glacial lake soils which are classed in the Clyde series. The greatest area devoted to sugar beets is invariably located within the lake basins and upon soils of the Clyde series.

The case in Ohio is even more marked than in Michigan. All of the Ohio counties which report more than 200 acres of beets are so located as to be dominated by the soils of the Clyde series. They lie in or adjacent to the area of the ancient glacial Lake Maumee. The soils are chiefly members of the Clyde series, with the Clyde clay, clay loam, and loam most extensively developed. In this region extensive tile underdrainage has rendered even the more claylike and compact soils suitable for beet growing.

The association of beet-growing areas and the presence of soils of the Clyde series is not so obvious in Wisconsin as in the other two States. This arises from the fact that the soils of the Clyde series are distributed through a large number of small local lake basins in the main, and the details of beet production are not sufficiently precise to permit of close correlation with these small and scattered areas. Yet a field examination of the territory shows that the soils of the Clyde series in Calumet, Fond du Lac, Kenosha, Milwaukee, Racine, and Waukesha Counties are utilized for beet growing, while smaller areas in Dane and Rock Counties, together with other closely related soils, are the chosen ones for beet growing in these leading beet-producing counties of the State.

Among the soils of the Clyde series the Clyde loam is the best for beet production, although well-drained areas of the Clyde clay and portions of the Clyde fine sandy loam, which are particularly well supplied with organic matter in the surface soil, are also excellent beet soils. The yields upon the Clyde fine sandy loam are not usually so heavy as upon the Clyde loam, while the stiff surface soil of the Clyde clay does not favor the intensive tillage required by the growing crop, and it also offers considerable resistance to root penetration.

Both of these difficulties may be overcome by perfecting the drainage and by the careful preparation of the land prior to seeding to beets.

It is probable that the greatest acreage of sugar beets grown upon any one of the eastern soil types is produced upon the Clyde loam. Yet only a very small percentage of the total available acreage of this one soil has been utilized for sugar-beet growing.

If this and other well-suited types of the Clyde series were also used for sugar-beet growing the acreage devoted to this crop could be considerably increased in the humid region.

Until the soils of the Clyde series have been more completely occupied for beet culture there should be little extension of acreage upon other eastern soils not so well adapted to this crop, although certain upland soils of glacial origin[1] which are well drained and well supplied with organic matter are also available for an even greater development of the beet-sugar industry.

The production of sugar beets in the humid regions of the United States is of such recent origin and the areas within which beets are now grown are so localized that an account of the chief steps in the agricultural practice is essential to show under what conditions beet growing may profitably be undertaken upon added areas of the soils of the Clyde series.

It has been quite generally the custom to plant beets upon land which was in sod during the previous year. The beets thus take about the same place in the rotation as corn and frequently replace a part of the acreage formerly given to that crop. The preparation of the land for beets is about the same as for corn, except that deeper plowing is considered advisable to aid the taproot of the beet in its deeper development. It is essential that thorough cultivation should be given the land prior to planting, so that as many weeds as possible may be germinated and killed before the seeding of the crop. Beets will stand some degree of frost and may be planted at an early period, usually in the latter half of May, even in the more northern localities. The land must be dry at the surface, for standing water will always give an uneven germination and incomplete stand of the plants.

Special beet drills are used and the rows are variously spaced, but usually at 24 to 28 inches. The drills sow the seed thickly, and the crop must be thinned to a stand after the tops have grown to a height of about six inches. This is done entirely by hand labor. Frequently the companies for which the beets are grown contract to furnish all of this hand labor at a stated price per acre. The beets are also hoed once or twice during the season by the best growers, and the sides of the ridges are lightly dressed with the hoe at these times.

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[1] The deep phase of the Miami silt loam, particularly in southeastern Wisconsin, is one of the most extensive of these soils.

Frequent cultivation with horse cultivators is essential, and the most successful growers state that the more frequent and the deeper the cultivation the larger the crop. All of the horse labor in connection with the tillage of the crop is performed by the farmer who contracts the acreage.

Under ordinary climatic conditions the crop is ready for harvesting in the middle or latter part of September, throughout the Great Lake region. The first step is that of lifting the beets. This is accomplished by the use of a special tool, built like a large subsoil plow with narrow flanges set to raise the earth as the plow passes between the rows. The beets are thus loosened in the soil. They are pulled by hand and this labor is usually furnished by the company at a fixed charge per acre. (See Pl. V, fig. 2.) The beets are topped in the field as they are pulled (Pl. V, fig. 2, and Pl. VI, fig. 1) and the roots are loaded on wagons (Pl. VI, fig. 2) for transportation directly to the factory or for weighing in (Pl. VII, figs. 1 and 2) and shipment by rail (Pl. VIII, figs. 1 and 2). When weighed, the beets are also sampled to secure representative roots for analysis, as the majority of the factories pay for the beets upon the combined basis of tonnage and sugar content.

The fertilization of lands upon which beets are grown has not been varied greatly from the common farm practice for corn. Stable manure is applied either to the clover sod before plowing or to the beet land after it has been plowed. Even this is omitted in the majority of instances and only the rotting vegetation is depended upon for direct fertilization. Some few growers have used small quantities of complete commercial fertilizer upon beets. From 200 to 300 pounds of a formula commonly used for corn has been used. It analyses about 3 per cent of nitrogen, 9 per cent of phosphoric acid, and 3 per cent of potash. Upon much of the land now used for beet culture it is probable that the use of commercial fertilizers is not fundamentally necessary. Yet the use of lime, in the form of ground limestone, quick lime, slaked in the field and applied broadcast, or the refuse lime from the beet factories would prove decidedly beneficial. Few farm crops are more favorably affected by liming that the sugar beet. It is also desirable that large amounts of organic manures should be thoroughly incorporated with the surface 7 to 9 inches of soil. This is the reason for the general use of clover sod for beet growing. Where possible it would be good practice to apply stable manure to the clover sod before turning it under for the beet crop. This may be done immediately before plowing, or the manure may be broadcasted over the grass land the year previously so that its first effects are gained by the growing grass and the residual benefits are secured by the beets.

The prime necessity for securing large yields of beets upon the Clyde loam and, in fact, upon all of the heavier soils of the Clyde series is adequate drainage. This should be perfected not only for the surface of the land but also for the subsoil to a depth of 2 or 3 feet. It can only be made most effective and more nearly permanent when it is accomplished through thorough tile underdrainage. The outlets for complete farm drainage are usually provided by the county and township ditches and nearly every farm on the Clyde loam or clay loam may be connected with such outlets.

For complete drainage on such dense soils as the Clyde loam, clay loam, and clay, lines of tile should be located at intervals of not more than 60 feet while an interval of 40 feet is not too close in many cases. The tile should be laid at a minimum depth of 2 feet to 30 inches and tile of smaller inside diameter than 4 inches should not commonly be used. The best beet fields upon both the Clyde loam and clay were invariably found to be tiled. The more adequate drainage resulted both in a more nearly perfect stand and in the added length and weight of the mature beets. Danger from poor germination was avoided in the early part of the season, while greater root penetration into the more porous and friable soil gave greater opportunity for maximum growth than upon any of the fields not tile drained. It is estimated by some growers that the cost of tiling the fields is repaid by two or at most three beet crops through increased tonnage and higher sugar content of the beets. Other crops grown in rotation with the beets are, of course, correspondingly benefited.

The yields obtained upon the several soils of the Clyde series have been stated in the general discussion of the different types. For the sake of comparison they may be restated.

While the more sandy members of the series may be used locally for beet growing this is not advisable, and the Clyde fine sandy loam is the coarsest textured soil upon which good yields are consistently obtained. The Clyde fine sandy loam gives average yields of 10 to 12 tons per acre. The Clyde loam produces 7 to 10 tons per acre upon lands not tile drained, and yields of 12 to 18 tons per acre upon tile-drained lands where the greatest care is exercised in the preparation of the land and the fertilization of the beets. It is probable that the general average for the type is in excess of 10 tons per acre, ranging upward on the better drained portions of the type and downward upon lands where drainage is not so complete. A few areas of the Clyde silty clay loam, which have been planted to beets give large yields of relatively low sugar content. The yields are reported to range from 12 to 18 tons. In almost all cases these yields were obtained upon new land, recently drained and placed under cultivation. It is probable that as this soil is used longer for beets and other crops that the tonnage will somewhat decrease and the sugar content increase. The Clyde clay gives average beet crops ranging between 10 and 12 tons per acre. In northwestern Ohio yields of 15 tons per acre upon well-drained areas of the Clyde clay are not at all unusual. The region where the beets are grown upon the Clyde clay in the Maumee Basin is rather more calcareous than the average, and there has been a general adoption of tile underdrainage.

It is probable that under equal conditions of skill in growing and with all lands properly tile drained, the valuation of the soils of the Clyde series for beet production would about follow the average mechanical composition of the types. The Clyde fine sandy loam would be the coarsest grained soil generally advisable for the crop. The Clyde loam, because of its wide distribution, would remain one of the most important soils for this crop. The Clyde clay would become of far greater importance than at present, but only on the completion of added drainage facilities. The largest yields per acre might be expected from the clay, but the majority of farmers under the natural conditions would probably find that the Clyde loam was the safest soil upon which to plant the crop. It is certain that only limited areas of other upland soils will be found to compete on even terms with these soils of the Clyde series for the extensive and long continued cultivation of beets.

BEANS.

While beans are chiefly grown upon upland soils, both in southern Michigan and western New York, they are also produced upon the better-drained areas of various members of the Clyde series. In Michigan the six leading counties in acreage and production of beans are all counties which contain considerable areas of the more sandy members of this series. These and the upland soils both contribute to the success of bean production.

In New York State, the connection between the soils of the Clyde series and the production of beans is not so close, chiefly because the larger areas of the Clyde soils are not so well drained either naturally or artificially as in more western occurrences.

The soil surveys which have been made in both States show that for bean production the more sandy soils of the series and the better drained areas of the Clyde loam are the soils of the series most successfully used for bean growing. Beans are not reported as a principal crop upon any of the types more dense than the loam, while the larger acreages are always found on the Clyde sandy loam and Clyde fine sandy loam. From the soil survey reports it is possible to give a general idea of the average yields from the different soil types of the Clyde series. The bean yields upon the Clyde sand are obtained from a small acreage only, but average from 12 to 16 bushels per acre. The yields upon the Clyde sandy loam range from 8 to 20 bushels, with an average around 12 bushels per acre. The small area of the Clyde stony sandy loam, probably because of better drainage, shows a range in yields from 10 to 20 bushels per acre. The Clyde fine sandy loam is one of the types of the series particularly well adapted to bean growing, and the yield is given as ranging from 10 to 25 bushels per acre. It is probable that the general average for the type is about 15 bushels. The portions of the Clyde loam which are particularly well drained are found to give large crops of beans, and the yields range from 18 to 25 bushels per acre, with an average probably exceeding 20 bushels. Such a field is shown in Plate IX, figure 1. There is an excellent opportunity to extend bean production upon this soil as additional areas are improved with tile underdrainage. Beans should constitute a part of the regular crop rotation on the best drained areas of the Clyde loam and should be increasingly grown where the somewhat more profitable sugar-beet crop has not been introduced or may not be grown at present because of distance from shipping point or factory.

Beans require a well-drained soil, naturally well supplied with organic matter, mildly calcareous, and in good fertile condition. They may be grown upon less desirable soils, but the most profitable crops are always secured upou land as fertile as is required for the production of a good crop of corn. For beans the soil must be warm and well drained in order to give good germination and a consequent complete stand. The land should be stone free so that improved machinery may be used to the best advantage for the harvesting of the crop, yet good yields may be obtained upon gravelly and even stony soils.

The best farm practice tends toward planting beans rather late in the season after the surface soil has become well warmed and is in good condition to give high germination, since beans are intolerant of wet, cold weather at planting time. Frequent shallow cultivation is required during the season. Many growers depend upon the residual effects of stable manure applied to a corn crop for the fertilization of the bean crop. Others plant upon stubble land and use small quantities of fertilizer containing a large proportion of phosphoric acid, a smaller proportion of potash, and little nitrogen.

Harvesting usually is accomplished by the use of special machinery which pulls two rows of beans at a time and throws the vines into a windrow from which small bunches are formed by hand. The beans are field cured and usually carried to the barn for more complete curing before thrashing. The harvesting is frequently delayed until after the first light frosts of autumn.

A yield of less than 14 to 15 bushels of beans per acre is not usually profitable because of the amount of labor required for the care and harvesting of the crop. The best growers, especially upon well-drained land, obtain yields which range from 18 to 25 bushels. These are decidedly profitable, and beans should constitute an important field crop upon all of the better drained and more porous members of the Clyde series of soils.

CABBAGE, ONIONS, AND CHICORY.

Cabbage is grown on a small acreage upon several types of the Clyde series. Upon the Clyde sand and fine sandy loam cabbage is produced for local markets and constitutes an early special crop. The yields range from 8 to 14 tons per acre and the crop is ready for market in August or early September. The total acreage, thus grown, is small and confined to the near vicinity of city markets.

Cabbage is also grown as a shipping or storage crop upon the heavier members of the Clyde series, particularly upon the Clyde loam, clay loam, and silty clay loam. The acreage on the Clyde loam is small, but the yields obtained are fair. A production of 8 to 15 tons per acre of marketable heads is common.

The Clyde clay loam and silty clay loam are far more extensively used for cabbage growing than any other members of the series. In the vicinity of Racine, Wis., several hundred acres of cabbage are annually grown, both for the local city markets and for shipment to southern cities. Danish Ball Head, Flat Dutch, and other shipping varieties are chiefly planted. The crop is grown in regular rotation with other field and truck crops and the average yields vary from 10 to 15 tons per acre, dependent upon seasonal variations, chiefly. It has been found that cabbage should follow onions in the truckers rotation, while they may be grown upon clover sod or after corn in the general farming rotation. Cabbage should not be grown more frequently than once in four years upon the same land in either rotation. This interval is essential to assist in the control of fungous diseases. It is a good practice to lime the land where cabbage is to be grown, using either a ton of burned lime per acre or an equivalent in the form of 2 or more tons of ground limestone. The source of supply for the latter material is near at hand in the case of the Racine, Wis., area and not usually remote in other instances. Stable manure, plowed under in the fall before the crop is planted, constitutes one of the best fertilizers for cabbage, while various commercial fertilizers in moderate amounts are used by some truckers. Usually, the general fertility of the soil is chiefly depended upon for the growing of cabbage upon the Clyde soils. The yields obtained are high under these circumstances. Wherever there is a fair local market or an opportunity to ship to advantage, cabbage growing might well be extended upon the heavier soils of the series.

FIG. 1.—A TYPICAL FIELD OF NAVY BEANS AS GROWN ON THE SOILS OF THE CLYDE SERIES, NEAR FLINT, MICH.

FIG. 2.—UNDRAINED CLYDE FINE SANDY LOAM. BIRCH, TAMARACK, AND RUSHES THE ONLY PRODUCT.

FIG. 1.—A COUNTY DRAINAGE DITCH IN CLYDE LOAM.

Hundreds of square miles of this productive soil have been reclaimed for agricultural uses in this manner.

FIG. 2.—CLEARING THE CLYDE CLAY IN PREPARATION FOR TILE UNDERDRAINAGE.

Note the excellent crop of corn on land already tiled.

Onions are grown to some extent upon various soils of this group. The Clyde fine sandy loam is the type best suited to onion culture, although the Clyde clay loam when well drained and in good physical condition at the surface also constitutes an excellent soil for the crop. On the Clyde fine sandy loam onions yield from 300 to 500 bushels per acre under ordinary conditions of cultivation, while crops in excess of 800 bushels are reported upon the well-drained and heavily fertilized land. The crop is benefited by the application of large quantities of stable manure and by the use of fertilizer high in nitrogen and potash. The use of considerable amounts of organic manure is necessary for the best results with onions upon the Clyde clay loam, as the surface soil must be rendered rather more friable than in the ordinary field condition.

Chicory has been grown as a special crop upon the Clyde sand and Clyde sandy loam in certain parts of Michigan. Both of these soils give yields of approximately 10 tons per acre. The acreage devoted to the crop is rapidly diminishing since other more profitable crops may be grown upon both soil types.

VEGETABLES.

In the vicinity of the larger cities the more sandy members of the Clyde series are used to a rather small extent for market gardening. Wherever drainage has been installed and where stable manures may be obtained from city or other sources the Clyde sand, fine sand, and sandy loam constitute excellent market-garden soils.

Early Irish potatoes, string beans, cucumbers, cabbage for summer marketing, cauliflower, tomatoes, and other garden vegetables are successfully grown upon all of these types. It is probable that celery would prove successful and profitable upon the Clyde sandy loam and fine sandy loam, especially where irrigation of the beds is possible.

DRAINAGE.

Until some form of artificial drainage was instituted, large areas of the different types of the Clyde series in all localities could not be occupied for any form of agriculture more intensive than the grazing of cattle during periods of especially dry weather. The larger part of all of the types now classed as soils of the Clyde series existed only in a swampy condition when the region where they are found was first explored. The northwestern counties of Ohio were long known as the "Black Swamp" country, and it was not until within the last 40 years that any great progress had been made toward the occupation of this land for planting. The adjacent portion of Indiana was similarly a vast swamp until recent times. The region around Saginaw Bay was little used for farming before the early eighties. Even yet there are thousands of acres of the fertile soils of the Clyde series, located in New York, Ohio, Indiana, Michigan, and Wisconsin, which are either swampy or in such poorly drained condition as to produce only hay or grass for pasturage. Other extensive areas remain in tracts of forest consisting of water-loving trees and undergrowth. (See Pl. IX, fig. 2.)

In so far as the soils of the Clyde series have been reclaimed for agriculture, this has been accomplished through the extensive surface and under drainage of the lands so used. In nearly all of the larger areas occupied by soils of this series, drainage has already been accomplished through community effort in the construction of the larger drainage ditches and through individual effort in the draining of the farm lands into these outlets. This is the present condition in the Maumee Basin, in the Saginaw Bay region, and to a less extent in the smaller areas in Wisconsin where the Clyde soils are found. Such a county drainage ditch is shown in Plate X, figure 1.

There is no single improvement in the condition of the soils of the Clyde series so essential to crop production as drainage. It is not sufficient to provide extensive open ditches for conducting away the surface waters. It is just as essential to provide complete tile underdrainage for the more dense members of the series, in order to reduce the amount of moisture held within the soils and deeper subsoils. The tiling of such land is shown in Plate X, figure 2. Only the shallow rooted crops may be successfully grown upon the Clyde loam and the heavier members of the series until tiling is installed. The largest crop yields observed in any of the soil surveys and during the special examination of the different soils of the series were always located upon tile-drained land or upon land which was so situated as to require little artificial drainage to supplement unusually good natural conditions. The widest ranges in crop adaptations were also closely associated with good natural conditions, or with artificial drainage to supplement unusually good natural conditions.. It would scarcely be possible to overestimate the value of drainage for the soils of this group.

When drained, the soils of the Clyde series are almost universally of great natural fertility and of well-sustained producing power. They are composed of a heterogeneous mixture of many minerals; they are almost universally well supplied with lime—in the subsoil, at least; and they are unusually well provided with partly decayed organic matter in the surface soil. Through these characteristics they are easily worked and friable to a degree unusual in heavy, close-grained, swampy soils. Both the lime and the organic matter assist in maintaining good tillable condition, if the soils are handled with a normal degree of skill.

It is, therefore, very desirable that artificial drainage should be extended in areas where it has already been begun and that steps should be taken to reclaim these fertile and valuable soils in regions where community soil drainage and even local farm drainage are not yet practiced. The value of the reclaimed land is always sufficient to repay the expenditure for any well-planned drainage operations upon the soils of the Clyde series. This has been proved by the success attained in the drainage of hundreds of thousands of acres of the different types.

Many problems of engineering are involved in good tile drainage. For discussion of these the person particularly interested is referred to Farmers' Bulletin No. 524 of the United States Department of Agriculture. Also to the Special Bulletin No. 56 of the Michigan Agricultural Experiment Station and to numerous other experiment station bulletins.

SUMMARY.

The Clyde series includes types with dark-colored surface soils, usually well filled with organic matter, underlain by gray or mottled subsoils.

They have been formed as glacial lake sediments, as terrace deposits along glacial streamways, and as accumulations in small ponds, lakes, or in other positions of obstructed drainage within the glaciated region of the northern United States. The deeper subsoils of the finer grained members of the series are usually calcareous; that is, they contain more than 1 per cent of lime carbonate.

The soils of the Clyde series have been encountered in 37 different areas of which soil surveys have been made, located in 7 different States, and covering an aggregate area of 1,877,700 acres.

They are chiefly found in level or depressed areas within the glacial lake and river terrace province.

Because of the level topography and of prevalent dense subsoil conditions, the different soils of the Clyde series were usually swampy or very poorly drained in their natural condition.

Soils of the Clyde series are found at all elevations from approximately 250 to 800 feet above sea level, throughout the region of the Great Lakes. Usually there is little topographic relief in any small area and the slopes are gentle. Some members of the series consist of low ridges or gently undulating plains.

The soils of the Clyde series are divided into 11 different types upon the basis of differences in texture. These range from gravelly sand to clay.

The crop adaptations of the different soils of the series are given in detail in the text of the bulletin for the different localities in which they occur.

Sugar beets are the most important special crop. A large part of the eastern-grown sugar beets is produced upon the Clyde loam, fine sandy loam, and sandy loam, and even upon the better drained areas of the silty clay loam and the clay. The average yields from the different types show that the tonnage and sugar content of the beets grown upon the Clyde loam and Clyde clay are usually greater than upon any other soils of this or other soil series.

Beans constitute another special crop grown upon the better-drained areas of the soils of the Clyde series, particularly upon the Clyde loam and more sandy types. Good drainage is the chief essential to the production of large yields.

Cabbage, onions, celery, and chicory are locally grown for nearby city markets or for shipment.

Drainage is the most important of all forms of soil improvement upon the soils of the Clyde series. Proper drainage not only increases the yields of crops now grown but also widens the crop adaptations of the different soil types.

Extensive areas of the soils of the Clyde series have been brought under cultivation by means of artificial drainage. Other areas still remain undrained. In the case of these soils the cost of tile drainage is usually repaid within a short time by increased crop yields.

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No. 142

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December 29, 1914.

THE MIAMI SERIES OF SOILS.

By J. A. Bonsteel, *Scientist in the Soil Survey.*

INTRODUCTION.

The Miami series comprises an important group of soils which are distinguished by prevailing brown, light-brown, or gray surface soils and yellowish-brown or darker brown subsoils. In the heavier members of the series, especially where the natural drainage is not complete, the deeper subsoils are mottled with shades of brown and gray.

The topography of the different members of the series ranges from nearly level or only gently undulating to more rolling and ridged. Locally, sharply sloping ridges and small areas in which erosion has developed a choppy surface are encountered. By far the greater part of the area occupied by the important types of the series is best described as gently undulating to moderately rolling.

The natural drainage over a large part of the territory occupied by this series is fair to good. In the more nearly level tracts, particularly of the heavier soils, artificial underdrainage is highly beneficial.

In its original condition practically the entire extent of territory occupied by the soils of this series was heavily forested with hardwoods. Beech was the dominant growth on the more nearly level tracts, while sugar maple was most commonly found in the more rolling and better drained areas. Associated with these trees were walnut, several species of oak, basswood, and elm and ash, the two latter in areas where drainage was markedly deficient.

The soils of the Miami series are all derived from a thick sheet of glacial drift which covers the general region of their occurrence, extending to depths varying from a few feet to more than 350 feet.

The deeper subsoils of the Miami series are generally calcareous to a varying degree, but it is a common characteristic of practically all of the surface soils that they are lacking in lime, and their agricultural value is generally increased by the addition of this material.

Note.—This bulletin is of interest to those engaged or desirous of engaging in farming in the North Central States.

The soils of the Miami series do not occupy all the territory within which they are developed. In addition to these soils, and closely associated with them in the lower peninsula of Michigan and in portions of central Wisconsin, are those of the Coloma series. The latter are distinguished by light-brown to gray surface soils, yellow or reddish subsoils, and by their derivation from noncalcareous materials. They are prevailingly more gravelly and sandy than the soils of the Miami series.

Throughout all of the more nearly level areas occupied by the Miami soils there are large and small areas of soils which have dark-gray or nearly black surface soils and gray, drab or mottled subsoils. These soils are classed in the Clyde series, and are distinguished by the large quantities of organic matter which have accumulated in the surface soil. They occupy areas in which obstructed drainage gave rise to small ponds, or to swamps. They occur in the depressions and level areas lying between the low swells and ridges occupied by soils of the Miami series.

Toward the western boundary of the Miami series these soils are associated with dark-brown or black soils, which are classed as the Carrington series. Originally the Carrington soils were mainly prairie. They are of glacial origin, and usually calcareous in the subsoils, but are distinctly and uniformly much darker in color than the soils of the Miami group.

In nearly every area in which the soils of the Miami series are encountered there are also found extensive areas of water-worked and stratified soils of glacial origin which were deposited either as terraces along streams issuing from the melting ice or in the form of nearly level outwash plains of varying size. Several different series of soils have thus been formed. They are all distinguishable from the soils of the Miami series through the presence of stratified beds of sand and gravel at or near the surface and through the predominance of gravelly and sandy soils.

GEOGRAPHICAL DISTRIBUTION.

The soils of the Miami series occur most extensively in the western part of Ohio, the central and northeastern part of Indiana, in southern Michigan, south of a line connecting Bad Axe and Muskegon, in the Traverse Bay region of Michigan, in extreme northeastern Illinois, throughout eastern Wisconsin, and in a portion of the upper peninsula of Michigan, adjoining Green Bay. The location of the Miami series of soils is shown in figure 1.

The eastern boundary of the region dominated by the soils of the Miami series extends southward from the vicinity of Tiffin, Ohio,

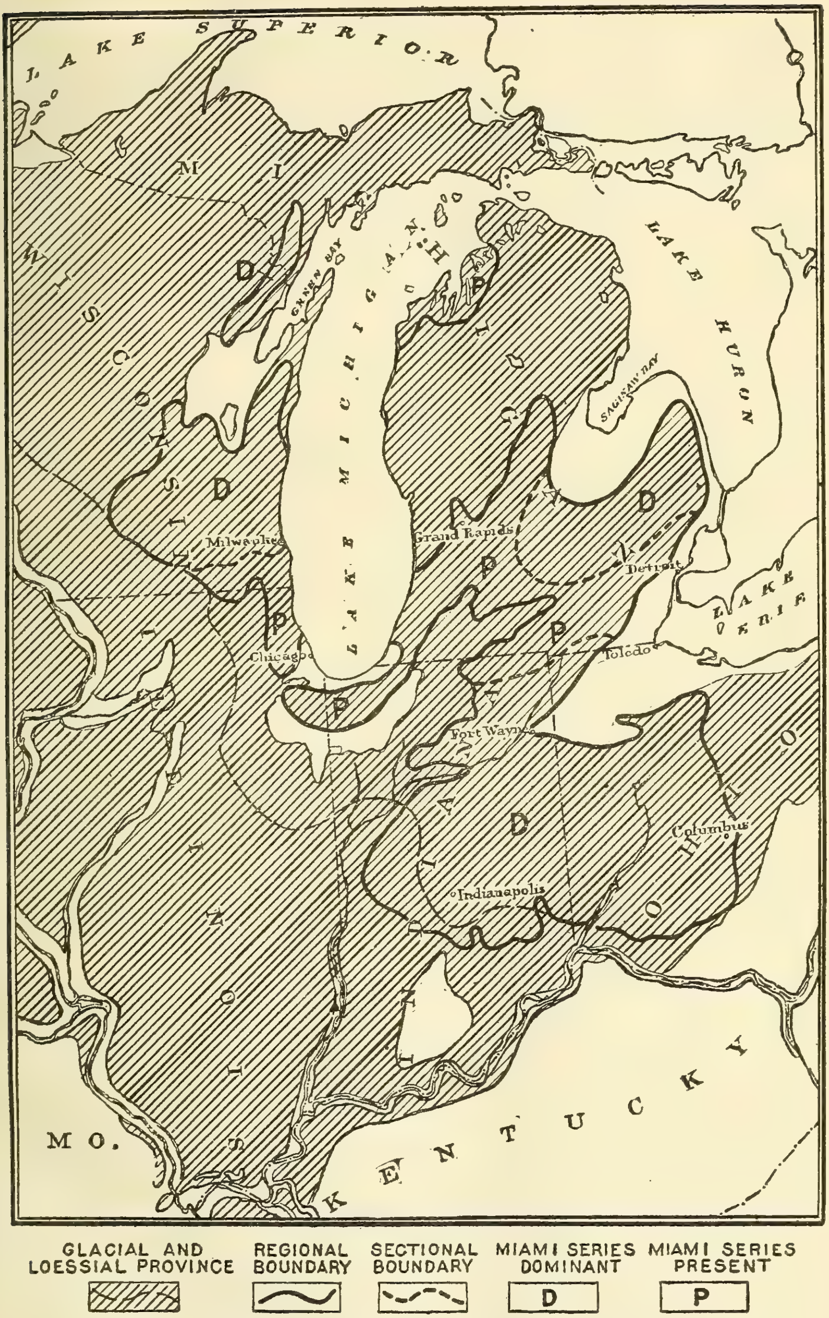

FIG. 1.—Map showing distribution of the Miami series of soils.

through Bucyrus and Columbus to the vicinity of Chillicothe. The line is irregular, and coincides roughly with the eastern boundary of the Scioto Basin. From the vicinity of Chillicothe the southern boundary extends generally westward through Hillsboro and Hamilton, Ohio, to the Indiana State line. In southeastern Indiana the southern boundary is irregular and crenulated, swinging north nearly to Connorsville, and thence southwestward through Greenburg to a point some 20 miles southeast of Columbus. Thence it extends northwestward through Columbus and Martinsville nearly to Greencastle. From this point the western boundary of the region extends in a generally northward direction, following approximately the course of the Wabash River, between Logansport and Covington. Between the Wabash and Tippecanoe Rivers a large area of the soils of this series extends westward to the eastern part of Pulaski County. The western boundary thence swings eastward to the vicinity of Warsaw, and northward in a very irregular line to Elkhart. From this point it crosses into Cass County, Mich. In southwestern Michigan the soils of the Miami series are so intimately associated with those of the Coloma series and with the soils of the extensive outwash plains that it is almost impossible to establish boundaries between sections dominated by the soils of the Miami series and those in which soils of other series predominate. However, along the border of Lake Michigan and extending around its southern end there is a belt of rolling and elevated territory within which the Miami soils are decidedly important. This belt stretches from the vicinity of Kalamazoo through the extreme southwestern part of Michigan, around the end of Lake Michigan, but at some distance from the shore.

From Tiffin, Ohio, through Fostoria and Findlay to the north of Lima, Ohio, and thence to the vicinity of Fort Wayne, Ind., the soils of the Miami series are bordered to the north throughout the Maumee Basin by an extensive, nearly level area, in which the soils of the Clyde series are the most extensive. There are a few small areas of Miami soils within this basin of the Maumee River.

From Fort Wayne, Ind., the eastern boundary of the area within which the soils of the Miami series predominate extends in an almost due northeasterly direction to a point in the "thumb" of Michigan immediately north of Bad Axe. To the east and south of this line the soils of the Clyde series are extensively developed between the area of Miami soils and the shores of the Lakes. In the Saginaw Bay region the boundary of the Miami series extends southwestward from near Bad Axe to the vicinity of Flint and thence westward to a point a little to the northwest of St. Johns, Mich. Thence it follows an irregular course to the north as far as the northern boundary of Gladwin County, thus extending around the shore line of Saginaw Bay at a distance varying from 25 to 50 miles inland.

From the southwestern corner of Ogemaw County, Mich., the boundary of the area within which the soils of the Miami series are chiefly developed extends southwestward to the vicinity of Newaygo, Mich., and thence southerly near the shore of Lake Michigan to St. Joseph. It will thus be seen that a large total area in the southern part of the lower peninsula of Michigan is occupied by the soils of this series, although soils of the Coloma and other series derived from the glacial outwash are closely associated with the soils of the Miami series, and that in some localities, as along the southern boundary of Michigan between Hillsdale and Three Rivers and thence northward to Kalamazoo, the soils of the Miami series occupy only a small part of the territory.

A disconnected area of soils of the Miami series is also encountered in the Traverse Bay region. It occurs as a narrow belt of elevated land along the eastern shore of Lake Michigan, extending from the vicinity of Manistee to Traverse City, Mich., and as a broader belt between Great Traverse and Little Traverse Bays.

In eastern Wisconsin the western boundary of the area dominated by soils of the Miami series extends from the immediate vicinity of Beloit northwestward through Madison and thence northward to the vicinity of Portage, Wis. Thence it extends irregularly northeastward to a point west of Oshkosh. Nearly all of the territory lying between this line and the western shore of Lake Michigan is occupied by the soils of the Miami series, although large areas of other important soils are intimately associated with them. This section is separated from a more northern area of Miami soils by the glacial lake deposits and by other soils of glacial origin covering a considerable area in the lowlands which surround the southern end of Green Bay, and extend south and west of Winnebago Lake.

While the regions as outlined contain all of the larger areas of soils of the Miami series which have been mapped in the progress of soil-survey work, it is probable that small local areas of the soils of this series may be encountered to the west of the territory indicated. There is little possibility of any extensive areas occurring in more southern and eastern localities. It should be held in mind that a wide variety of other soils of different origin and of different characteristics is associated with the soils of the Miami series within the area where these soils constitute the most extensive types, and the most important in agriculture. The detailed soil surveys of the individual county areas only can show the relative extent of the Miami and other soils and their intricate geographical distribution.

PHYSICAL FEATURES.

The soils of the Miami series occur in the northeastern part of the great Central Plain, which extends from the region of the Great Lakes southward beyond the Ohio River and westward beyond the Mississippi. The greater part of this area, especially the extensive tracts in western Ohio and in central Indiana, is drained by streams belonging to the Mississippi drainage system. Large areas in the northern region are drained by the small tributaries of the Great Lakes. In general, the region consists mainly of extensive plains which range from about 600 feet in altitude to extreme elevations of 1,500 feet above sea level.

The broader features of topographic relief within this region are primarily due to the elevation of the rock floor which underlies the surface deposits. The eastern border of the region is indistinctly separated from the more elevated Appalachian Plateau by a transition from the more rugged topography of the plateau to the gently undulating plains to the west. Along a large part of this border the difference in relief is not so pronounced as to form a distinct boundary, there being only a gentle gradation from hilly and dissected country into a region whose interstream areas are but gently undulating and within which the major streams occupy narrow or broad trenched valleys of no great depth. Along this eastern border the elevation of the plain ranges from about 700 feet, east of Chillicothe, Ohio, to approximately 900 feet immediately east of Columbus and about 1,000 feet to the east of Bucyrus. Near its eastern border that part of the plain occupied by the soils of the Miami series sinks gently toward the basin of Lake Erie, the northeastern border of the section following the ancient shore lines of the glacial lake which occupied the Maumee Basin. This shore line has an elevation of about 800 feet above tide level throughout its extent, from Tiffin, Ohio, to Fort Wayne, Ind. The eastern boundary of the area, extending from Fort Wayne to Bad Axe, Mich., has approximately the same elevation.

From the eastern border of this region in central Ohio the plains undulate westward, gradually increasing in elevation until a maximum altitude of 1,500 feet is attained over a small area in the vicinity of Bellefontaine. This marks the extreme altitude in an elevated ridge which extends in an almost due north and south direction from the vicinity of Bellefontaine to that of Hillsboro. This ridge varies from 25 to 40 miles in width and has an elevation of more than 1,000 feet. It constitutes a gently rolling watershed separating the drainage of the Scioto River from that of the Mad River and the Little Miami.

Another area within which the altitudes are greater than 1,000 feet lies along the southern portion of the Ohio-Indiana State line from near Portland, Ind., to the vicinity of Liberty. This rolling upland separates the drainage of the Miami River from that of the Whitewater River, while a branch of the same ridge lies between the latter stream and the eastern tributaries of the East White River. These ridges do not exist as distinct topographic features, but merely comprise the higher elevations in a rolling country between the principal drainage basins of southwestern Ohio and southeastern Indiana. With few exceptions, the local slopes and changes of elevation are very moderate. The plain merely swells to higher interstream ridges and sinks to the broad, terraced valleys of the present streams.

Toward the north the plain sinks in gentle undulations to the basin of Lake Erie and its continuation in the broad, flat drainage system of the Maumee River.

The greater part of central Indiana consists of a nearly level plain having a slight inclination toward the drainage basin of the Wabash River on the north and west and toward the course of the White River in the south-central part of the State. Along the Wabash this plain sinks to elevations of 700 to 800 feet. The southwestern and western borders of the region occupied by the soils of the Miami series do not greatly depart from the 700-foot contour line through much of this region.

North of the Wabash River the region is considerably more rolling, partly on account of the greater absolute elevation of the underlying rock formations and partly because the area is dissected by numerous large streams which have cut comparatively deep channels.

Beginning in extreme northeastern Indiana in the vicinity of Kendallville, an elevated area extends to the northeast past Hillsdale and Howell, Mich., to the vicinity of Lapeer. This rolling and ridged section has an extreme breadth of about 50 miles and lies chiefly above the 1,000-foot contour line. The elevation is due mainly to the altitude of the underlying rock which is near the surface, particularly in the vicinity of Hillsdale, and in part to the depth and ridgy character of the superficial glacial deposits over the more northern part of the ridge. From this ridge the land slopes to the southeast and the northwest in gently undulating or slightly ridged areas with intervening nearly level plains of varying size.

The only other elevations in excess of 1,000 feet in the section of southern Michigan where the soils of the Miami series prevail occur along the extreme northwestern border of the area.

The small detached area in the Traverse Bay region occupied by soils of the Miami series ranges in elevation from about 600 feet to approximately 900 feet above sea level. The elevations within small areas vary more widely in this section than in any other part of the more eastern development of the Miami soils. It is a territory of undulating to hilly topography, with small areas of nearly level land. The nearly level areas are chiefly occupied by soils of other series.

In general, the areas occupied by the soils of the Miami series in southern Michigan may be characterized as rolling to ridged in the more elevated portion as described, and as gently undulating plains through the greater part of central Michigan from Howell to the vicinity of Grand Rapids. The western and southwestern part of the lower peninsula is occupied by broad, low ridges parallel with the lake shore, with intervening extensive outwash valleys which do not usually comprise large areas of Miami soils.

The small sections of northwestern Indiana and northeastern Illinois included within the region of mainly Miami soils consist chiefly of broad, flat ridges whose highest elevations do not exceed 800 feet. The local variations in altitude are usually slight, and the slopes are gentle, except in minor areas.

In the portion of eastern Wisconsin which is largely occupied by soils of the Miami series the topographic features differ materially from those within the territory already described. The land along the western shore of Lake Michigan from Racine to the mouth of Green Bay has an altitude of about 600 feet, or an elevation of 20 to 40 feet above the level of the lake. From the shore of the lake it rises rapidly toward the west, elevations of 900 feet or more being attained along a line from the center of the Door Peninsula southwestward to the vicinity of Beloit, Wis. In part this altitude is caused by the elevation of the underlying rock floor; but the minor differences in elevation and slope, and to some degree the absolute altitude, are determined by the thickness of the superficial deposits which cover this region. The central ridge is marked by choppy, steeply sloping ridges with large and small intervening hollows and plains, which give an appearance of rugosity in marked contrast with the surface of the areas occupied by the soils of the Miami series in Indiana and Ohio. The rolling topography typical of southeastern Wisconsin is shown in Plate I, figure 1. Over a large part of the section in southeastern Wisconsin immediately west and northwest of the high central ridge there are long, rounded, nearly parallel hills which, with the intervening hollows, give a fluted aspect to the surface.

FIG. 1.—ROLLING TOPOGRAPHY OF THE MIAMI SERIES IN WAUKESHA COUNTY, SOUTHEASTERN WISCONSIN.

[Miami silt loam in the foreground; Miami gravelly loam on the hills.]

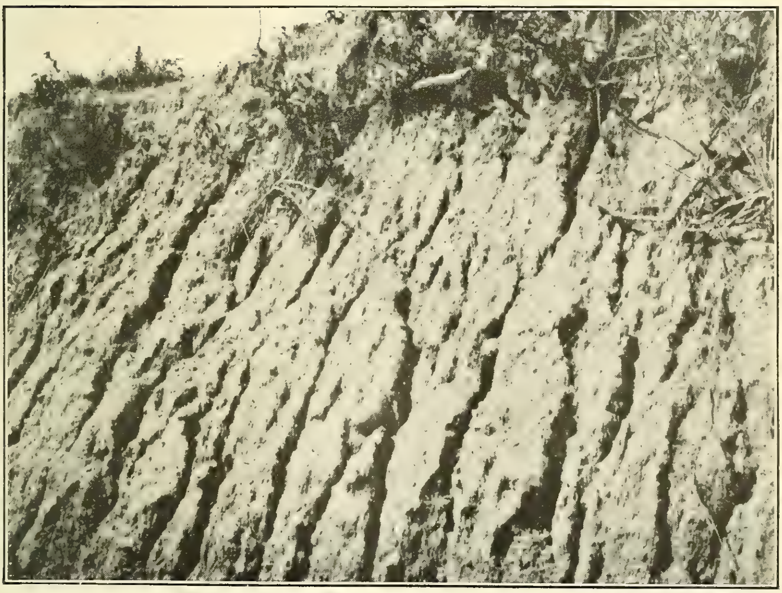

FIG. 2.—ROAD CUT IN GLACIAL TILL IN SOUTHERN MICHIGAN, SHOWING THE MINGLING OF STONES AND GRAVEL WITH THE FINER PARTICLES OF SAND AND CLAY.

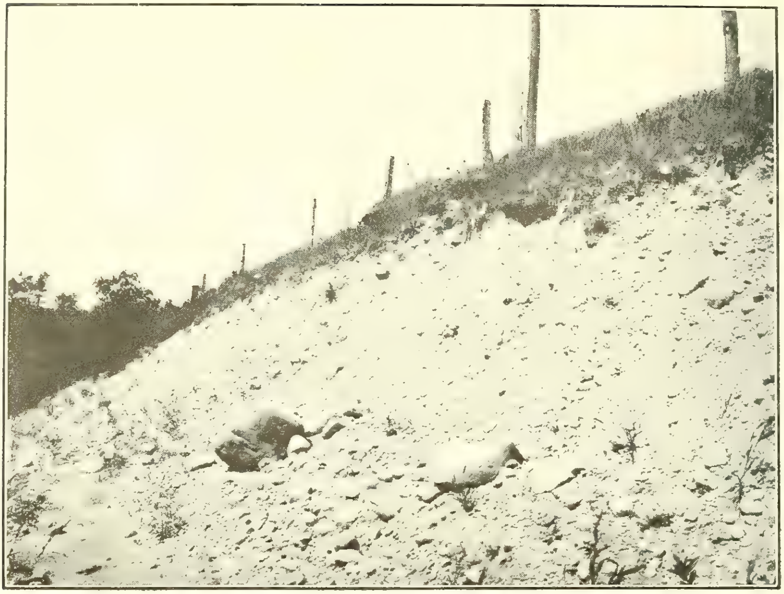

FIG. 1.—A CHARACTERISTIC CUT IN THE PARTIALLY WATER-SORTED DRIFT OF SOUTHEASTERN WISCONSIN.

[The material is sandy and gravelly, and gives rise to such soils as the Miami gravelly sandy loam.]

FIG. 2.—A LIMESTONE LEDGE, KEWAUNEE COUNTY, WIS.

[This rock underlies the rolling, glaciated upland. Glacial bowlders are seen in the stone fence.]

From this region the area occupied by the soils of the Miami series extends westward in broad, undulating swells, the elevation varying widely within the limits of a county, while smaller areas are usually smooth or rolling. A general elevation of 900 to 1,000 feet is maintained to the western border of the region of Miami soils near the Wisconsin River. Along the extreme western border some rough and hilly country is encountered within the known limits of the occurrence of soils of this group. The most notable example of this topography is found in the eastern end of the Baraboo ridge immediately west of Portage, Wis.

In general, the region occupied by the soils of the Miami series in Wisconsin not only possesses greater variations in elevation than the other sections dominated by these soils, but the local variations are greater, the slopes are more pronounced, and the surface is rougher and more complexly ridged than in the majority of the other regions.

ORIGIN.

All of the soils of the Miami series owe their origin to the glaciation of the region in which they occur.

Within recent geologic times practically all of the northern part of the continent was repeatedly covered by glacial ice. The ice advanced as far south as the region of the Ohio River and as far west as that of the Missouri. The successive advances and retreats of the ice each occupied a considerable period of time and gave rise to different deposits of materials which cover the central part of the United States to depths ranging from a few feet to a maximum of 400 or 500 feet.

The soils of the Miami series are developed chiefly within the territory which was most recently covered by the ice. This invasion is known as the Wisconsin stage of glaciation.

During the Wisconsin stage of glaciation the center of dispersion of the ice was undoubtedly within the region of the Canadian Highlands to the northeast of the Great Lakes. From this section the ice advanced as a thick sheet over all the territory to the south, extending as far as Chillicothe, Ohio, beyond Indianapolis, Ind., and into eastern and northeastern Illinois. It occupied the greater part of eastern and northern Wisconsin and covered considerable areas west of the Mississippi River.

In the region of the Great Lakes the ice sheet of the Wisconsin glaciation characteristically occupied the chief lines and basins of depression in the existing land surface in the form of broad tongues or lobes, which have been given the names of the important lakes, bays, and streams which now occupy these basins.

The ice sheet which occupied the basin of Lake Erie was continued southward in lobes which approximately coincided with the basin of the Scioto River, that of the Maumee and Miami Rivers, and another which extended westward through the Maumee Basin and overspread the northeastern and central part of Indiana as far as Indianapolis and the drainage of the Wabash River. From the deposits formed by this glacier the plains of western Ohio and eastern and central Indiana were formed, and these are extensively occupied by the soils of the Miami series.

Another large lobe of this glaciation extended southwestward through the Saginaw Bay region as far south as the northern part of Indiana. To the east its margin joined that of the Huron-Erie lobe, and the combined deposits of the two give rise to the rolling and hilly territory which extends southwestward from the "thumb" of Michigan to the vicinity of Logansport, Ind. It laid down the materials which constitute the ridged plains of central Michigan from Saginaw to the vicinity of Jackson and Kalamazoo. It did not extend entirely to the shore of Lake Michigan, but adjoined a larger lobe, which occupied the basin of Lake Michigan. Along the junction of these two lobes were formed deep and extensive deposits of ice-borne material along the eastern border of the lake from the vicinity of Newaygo to the Indiana State line.

The Lake Michigan lobe was almost coextensive with the present area of that lake, but extended slightly beyond its present boundaries, and laid down deposits which circle the lower extremity of the lake, giving rise to soils of the Miami series in northern Indiana and northeastern Illinois.

Another lobe of the Wisconsin glaciation extended to the southwest through the basin now occupied by Green Bay and Winnebago Lake. The front of this lobe and of the smaller Delavan lobe extended from the vicinity of Beloit, Wis., beyond Madison and Portage, and thence northward into central Wisconsin. Along the line of its juncture with the Lake Michigan lobe extensive and deep glacial deposits were formed which accentuate the area of highland separating the Green Bay basin from that of Lake Michigan.

When the ice sheet of the Wisconsin glaciation advanced to its extreme limit it extended over a region which had previously been glaciated one or more times. It filled the existing valleys and deeply covered the interstream ridges and hills. Its base rested upon the unconsolidated deposits of the previous invasions and upon exposed ledges of consolidated rock of various character and hardness. The ice scoured and eroded these surfaces, picked up masses of rock, gravel, sand, and clay, and after thoroughly mixing them transported the material a varying distance along its path. It is probable that a large part of this reworking and transportation was accomplished beneath the ice and in the lower zones of the glacier. At the same time other materials, frequently derived from remote sources, were carried within the upper part of the glacier and upon its surface.

The glacial advance to the extreme limits of the Wisconsin stage of glaciation occupied a long period of time. There is also evidence that the ice front remained stationary, or nearly so, along the region of its extreme advance for some time, resulting in the thickening of the ice-deposited material along the outer margin of the glaciated region, forming hills and ridges of some elevation. These deposits are technically known as moraines, and comprise the material carried under, within, and upon the ice and piled up as a heterogeneous mass of stone, gravel, sand, and clay where the ice was melting along a nearly stationary position at its terminus. The outer margin of the area covered by the Wisconsin stage of glaciation is quite commonly marked by such morainal accumulations. Sometimes these moraines are heaped against more elevated land, which arrested the advance of the ice. Such moraines occur along the southeastern border of the area under discussion, particularly from near Chillicothe, Ohio, to the vicinity of Lancaster, Ohio. In other locations the front of the ice rested upon a nearly flat surface, and the morainal front rises from the outer plain like a low, irregular wall. The southern border of the region occupied by the soils of the Miami series is chiefly of this character from Chillicothe westward to the Wabash River and throughout a great part of the southwestern and western margin of this stage of glaciation.

From this position of its extreme advance the ice slowly receded, with numerous periods of halting and some stages of readvance over territory which had been once freed from its ice cover. At each of the stages of halting large or small marginal moraines were formed which still exist as low, rolling ridges, usually occupying long, narrow belts of higher land arranged concentrically with the margin of the individual ice lobes and around the extremities of the basins through which the various ice sheets advanced and retreated.

Between these swelling and rounded moraines the material which was carried under and within the ice sheet was distributed in the form of a thick sheet of clay, sand, gravel, and bowlders known as glacial till. A cut in this material is shown in Plate I, figure 2. This material does not differ greatly from that of the thicker morainal accumulations, except in having a more nearly level surface and in the lack of linear ridging and hummocky surface features. In general there are more extensive areas of water-washed and stratified material at some points within the moraine areas than within the till plains, although the work of the water from the melting ice is recognized to some extent in each of these forms of glacial deposition.

Bowlders and larger stones are more numerous within the moraine areas, especially those crystalline and other extraneous rock masses which were in all probability carried at or near the surface of the ice sheet. Large areas of the till plains are nearly stone free at the surface.

It is characteristic of the Wisconsin stage of glaciation that the thickest and most hilly areas of morainal deposition were formed between the lobes of the glacier invading the Lake region. Along such interlobate lines both lobes of the glacier deposited the included earthy and stony material as the ice melted. Along such lines also the action of water upon the glacial material was pronounced and many of the interlobate moraines consist of true unstratified till, of hillocks and ridges of water-washed and partly assorted gravel and stone, and of nearly level sandy areas. The associated hillocks, ridges, basins, and hollows, largely formed from stratified material, are commonly called kames. They differ from the morainal areas chiefly in the predominance of stratified drift and to some extent in the presence of kettle-shaped hollows inclosed between sharp ridges and knolls. A characteristic cut in such stony and sandy material is shown in Plate II, figure 1.

The melting of the glacier was accompanied by a greatly swollen condition of the streams which issued from the ice front. These streams carried large quantities of gravel, sand, and silt southward to the uncovered drainageways of the larger rivers. As a result the lower courses of the majority of the streams from the glaciated territory are bordered by terraces of water sorted and washed material not included in the Miami series of soils. In some instances partial readvances of the ice sheet covered such stratified deposits with a later sheet of till, and there are large and small areas of the Miami soils within the till plains which are underlain at various depths with stratified deposits of such origin.

In many instances the glacial drainage issuing from the interlobate moraines carried out sorted material which was deposited over broad frontal plains in the form of outwash aprons and terraces along drainageways. While these areas do not give rise to soils of the Miami series, they are intimately associated with them, occupying extensive level tracts between the ridged moraine areas and bordering on the undulating or nearly level till plains. It is natural that considerable areas in southern and southwestern Michigan should be formed by such deposits, since the drainage from the interlobate region between the Saginaw and the Erie lobes and between the Saginaw and Lake Michigan lobes escaped to the southwest across the Michigan-Indiana line. This condition also gave rise to extensive upland areas where the glacial deposits are so evidently water washed as not to be included within the soils of the Miami series.

Another form of glacial deposits of less extent consists of the long, low, rounded hills, frequently elliptical in shape and made up chiefly of unstratified glacial material, which are known as drumlins. These hills usually occur in groups. The longer axes of the different ridges are as a rule approximately parallel, and the resulting topography is fluted and ridged with greater or less regularity. It is thought that these glacial forms were produced beneath the ice and that the direction of the longer axes marks in a general way the direction of ice flow. These hills are mainly covered by the unstratified glacial till, so that they are occupied generally by the same soils as the intervening till plains and the associated morainal ridges.

Along the southern and western margin of the region occupied by the soils of the Miami series and to some distance within its outer border the surface of the moraines and till plains alike is covered by a thin layer of distinctly silty, rather homogeneous and stone-free material. It is probable that this material originally was carried beyond the ice border in the form of fine sediment washed out by the water from the melting ice. It is also thought that it owes its present position over the uplands to the long-continued action of the wind, which, sweeping over silt-covered plains, carried large quantities of this fine earth over the upland, depositing it as a surface covering of varying depths over the moraines and till plains. Where this silty mantle, known as loess, attains a thickness of more than 3 feet, it gives rise to distinct soil types not included within the Miami series. In many cases it forms only a thin surface covering, as in large tracts in Indiana, Ohio, and Wisconsin, and in these localities the glacial till forms the deeper subsoil, the resulting soil type being classed as the Miami silt loam.

It is a common characteristic of all the materials which were mingled to form the moraines, the till plains, the drumlins, kames, and other forms of glacial drift, and which give rise to the soils of the Miami series, that the earthy mass and the included gravel and stone were derived from various sources along the path of the glacial invasion. It is probable that at the time of the latest stage of the Wisconsin glacial advance there were exposed extensive areas of the older drift sheets which mantled a large part of the region now covered by these later deposits. Numerous well borings and many exposures of the older drift in deeply cut stream channels show that it still exists and that the newer drift rests upon its surface throughout a great part of the general region of the Miami soils. Since it presented a soft, unconsolidated surface to the erosive action of the readvancing ice, it is more than probable that a very large part of the earthy material which was reworked into the later till sheet was contributed by this older till and its associated sandy and gravelly deposits. Through this unconsolidated material the local country rock had been exposed by water erosion occurring between the different stages of glaciation. As the ice readvanced over the surface of the region it picked up earthy material from the older till, mingled it with earthy and stony material from the various rock outcrops, and contributed varying amounts of extraneous material carried into the region from the areas of crystalline rocks which were exposed to glacial action in the territory north and east of the Great Lakes.

It is probable that a large part of the material derived from local sources was carried under the ice and within its lower sections. There is considerable evidence that such local materials were moved only short distances and rearranged and deposited by the melting ice to form the deeper part of the surface till covering. For this reason the local country rock exerts a strong influence upon the lithological character of the till sheet, in some cases giving rise to 90 per cent or more of the coarser stony particles which may be identified.

Thus, the ice of the Wisconsin stage of glaciation in its advance collected material from the limestones and shales of western Ohio and central and eastern Indiana, from the limestones, shales, and sandstones of the lower peninsula of Michigan, and from the limestones and associated shales which cover large areas in southeastern Wisconsin. Even where the limestone rocks do not directly underlie areas now occupied by the soils of the Miami series, broad areas of limestone lay directly across the path of the advancing glacial ice, as in the neck of the Saginaw Bay region, and, from exposed outcrops, contributions of earthy and stony material were obtained. It is also probable that materials derived from the remaining deposits of previous glaciation contained a fair percentage of such calcareous material. In Plate II, figure 2, a part of a ledge of the limestone which underlies portions of the Miami soils is shown.

The soils of the Miami series contain varying quantities of limestone bowlders, gravel, and rock flour in nearly all areas where they are mapped. This is particularly true of the deeper subsoil, which it is presumed most nearly represents the materials existing on the surfaces over which the ice moved. Examinations of the deeper subsoils show a general calcareous condition below depths of 1 to 2 feet, especially in the areas surveyed in Ohio, Indiana, and Wisconsin. The presence of the limestone or calcareous shale in the drift is not nearly so marked in southern Michigan as in other regions dominated by the Miami soils, but analyses of the drift indicate that as much as 25 per cent of the material is of a calcareous nature over considerable areas.

On the other hand, the surface soils of the different types in the Miami series are distinctly lacking in lime to a depth of 1 foot or more. Whether this condition is due to the original deposition of earthy material lacking in lime or is the result of the lime having subsequently been removed is not known.

The textural character of the rock prevailing in the different regions where the soils of this series occur has some influence upon the texture of the resulting soils. Thus, in the region of western Ohio, eastern and central Indiana, and a large part of southeastern Wisconsin, the most extensive areas are occupied by the clay loam and silt loam members of the series. These regions are also characterized by the presence of extensive beds of limestone and shale. These rocks in their original condition consist of rather finely divided mineral particles. Under the influences of glaciation they gave rise to fine-grained rock powder, and this was extensively worked into the till sheet. Some coarser particles were present, giving the material a sandy texture, and the gravel and stone are merely large fragments of rock which were not completely ground down by ice action. In the Lower Peninsula of Michigan and along the western border of the area occupied by soils of this series in Wisconsin, sandstones were much more generally exposed, and the loam and fine sandy loam types are extensively developed. In some parts of these sections the material derived from sandstone is so abundant that types of the Coloma series are intricately associated with the soils of the Miami series.

The thickness of the sheet of glacial drift from which the soils of the Miami series are chiefly derived varies considerably in different sections. It is usually greatest within the interstream areas and least where erosion has cut the valleys of the major streams deeply into the till plains. The drift is naturally somewhat thinner along the outer margins of the different areas than within the main areas of glaciation. Over the greater part of the area covered by these soils the total thickness of the glacial drift is made up of the combined depths of the latest till sheet and of one or more layers of older drift, although this condition is not universal. For these reasons the depth of the drift varies from a few inches to more than 500 feet.

Along many of the major streams which flow to the south from the glaciated region, such as the Scioto, the Mad, and the Miami Rivers of Ohio and the Whitewater and White Rivers in Indiana, ledges of rock outcrop along the crests of the slopes from the upland to the stream valley. In other instances the rock, whether limestone, shale, or sandstone, is only exposed in patches along the bed of the stream or in the narrow gorges of tributary brooks. Such exposures are usually absent over a large part of the main areas of glaciation. Only a few exposures of bedrock occur in southern Michigan, and they are by no means numerous in northwestern Ohio and northern Indiana. In eastern Wisconsin there are some clifflike outcrops of limestone where the deposits of drift are relatively thin and do not entirely cover the irregularities of the preglacial topography. They are most numerous to the east of the basin of Green Bay, from the center of the Door Peninsula southwestward beyond Fond du Lac. Ledges of limestone and sandstone are exposed also along the western margin of the glaciated area of southern Wisconsin, from the vicinity of Portage to Beloit, Wis. These mark the thin outer edge of the till sheet.

Within the main glaciated regions there are numerous small areas where the till sheet is only a few feet in thickness, and in some of these localities erosion has so far removed the surface covering that only the surface soils are derived directly from the till, while the deeper subsoils are formed from materials resulting from the partial weathering of the underlying rock. The total extent of these areas which are occupied by rock outcrop or by a thin veneer of glacial material over the local rock is so small that they are relatively unimportant.

It is probable that, taking the region as a whole, the depths of the different till sheets average as much as 150 feet and that the area in which the till covering is 100 feet or more in depth greatly exceeds that in which the average thickness is less than 100 feet. The depth of the later Wisconsin till alone varies from a few feet to more than 150 feet.

There is one other common characteristic of the majority of the areas in which the soils of the Miami series are extensively developed. Owing to the irregularities of surface configuration the region is one within which numerous large and small areas of ponded and obstructed drainage exist. In the regions of greatest variation in relief, such as in southern Michigan and eastern Wisconsin, there are numerous large and small lakes and many depressed areas which are either in a swampy condition or have remained poorly drained until within the time of human occupation. Even within the gently rolling to undulating region of western Ohio and central Indiana the hollows and extremely level areas were poorly drained in their natural condition. In all such localities there has been an accumulation of partially decayed organic matter which gives a distinctly black or very dark brown color to the surface soils. For this reason the surface of the broad region chiefly occupied by the lighter colored soils of the Miami series is frequently and repeatedly interrupted by large and small areas of these darker soils which have been correlated mainly with the soils of the Clyde series. Where such areas are of too small extent to be separated on the scale used

FIG. 1.—IRISH POTATOES ON THE MIAMI FINE SAND, COLUMBIA COUNTY, WIS.

[Yields of 150 to 175 bushels per acre are obtained.]

FIG. 2.—PASTURE LAND ON THE HILLY MIAMI GRAVELLY LOAM, WAUKESHA COUNTY, WIS.

[The rolling and hilly topography of this soil renders it somewhat unsuitable for tillage.]

FIG. 1.—DIVERSITY OF CROPS ON THE MIAMI FINE SANDY LOAM.

[Potatoes, cabbage, clover cut for seed, oat stubble, corn, and a hay field are shown in an area of less than 40 acres.]

FIG. 2.—APPLE ORCHARD ON THE MIAMI FINE SANDY LOAM IN THE MICHIGAN FRUIT BELT, NEAR GRAND RAPIDS, MICH.

[Note the rolling and rigid topography.]

in mapping the soils, some of them are included with areas of the Miami types. In other cases the surface covering of this dark-colored soil is too shallow to warrant the separation of such areas, and there are included within the limits of certain types of the Miami series small areas in which the surface soils are considerably darker than the average of the series. Such areas are in rather sharp contrast with the prevailing light-colored Miami surface soils, but are necessarily included with the more typical development.

The details of surface topography and drainage, of local variations in derivation and thickness of the soil-forming material, of degree of agricultural development, and of cropping systems can only be given in the detailed soil surveys of counties and other areas. From such surveys and from the examination of areas not yet covered by the soil survey the main characteristics of the different soils of the series are summarized.

TYPE DESCRIPTIONS.

MIAMI SAND.

The Miami sand is mapped in Waukesha County, Wis., over a total area of 1,920 acres. This type consists of a yellowish to brownish gray medium to fine sand 6 to 8 inches deep, underlain by a yellow, loose, incoherent sand of the same grade. The soil is very low in organic matter. Because of its loose, open structure it is easily cultivated, and can be worked under almost any moisture condition. Where the surface is not covered by a crop the sand is sometimes drifted by the wind, though not to any great extent.

Owing to the gently rolling to rolling topography, together with the loose, open character of the soil and subsoil, the drainage is excessive, and crops suffer from drought, except during seasons of unusually well distributed rainfall.

Practically all of the Miami sand is derived from glacial moraine material. The type was originally forested with a scrubby growth of bur oak, red oak, and white oak. At present hazel bushes cover a part of the type. The greater part of it is under cultivation, the principal crops being corn, oats, rye, and clover. When the rainfall is well distributed, fair yields are obtained. The land is not highly developed.

Soils like the Miami sand are better adapted to early truck crops than to general farming. For any crop it is necessary to increase the organic-matter content of the soil. This is best accomplished by frequently turning under green manuring crops and saving and applying all available stable manure.

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MIAMI FINE SAND.

Areas of the Miami fine sand have been encountered only in Columbia and Jefferson Counties, Wis. The total area mapped thus far amounts to 47,296 acres.

The Miami fine sand consists of a light-brown, loose, incoherent fine sand, which is low in organic matter. At about 9 to 10 inches in depth the material is light yellow, becoming lighter in color with depth, until at 30 to 36 inches it is almost white. The till bed, consisting of a mixture of sand, gravel, silt, and bowlders, is encountered at depths of 4 to 6 feet. Small quantities of limestone gravel and bowlders occur on the surface and throughout the soil section, but are seldom sufficiently numerous to interfere with cultivation.

The type is subject to some variation. On the lower slopes and in depressions the surface is darker and contains a larger amount of organic matter than the typical soil. Such areas are slightly loamy and have a somewhat higher agricultural value than the remainder of the type. In a few places a sticky sand is encountered at depths of 30 to 36 inches. A few gravel beds are scattered throughout the type, and such deposits have only a shallow surface covering of soil. Exposed areas are sometimes wind drifted, small dunes being formed. In general the Miami fine sand is both coarser in texture and lower in agricultural value than the Miami fine sandy loam, with which it is closely associated.

The topography varies from gently rolling to rolling. The surface is sometimes broken by sand dunes and depressions, though rarely to such an extent as to render cultivation impracticable. Owing to the loose, open structure of the material and to the surface configuration, the natural drainage is excessive and the soil as a whole is droughty. There are a few kettle-shaped basins and dune depressions which are not connected with drainage channels, and even in these places the drainage is usually sufficient, owing to the sandy nature of the deeper subsoil. Except during the heaviest rains, storm waters are rapidly absorbed by the soil and danger from erosion through surface run-off is reduced to a minimum.

The type is largely of glacial origin, being derived from the weathering of the glacial till, somewhat modified by wind and stream action. The weathering of the limestone fragments in the underlying till has a tendency to correct any acidity existing in the soil material, though this is often counteracted by leaching, leaving the surface soil more or less acid.

The original forest growth consisted chiefly of white, red, and bur oak, with some hickory and hazel brush. All of the merchantable timber has been cut, but the scrubby growth of oak and hazel bushes has been allowed to remain on a few of the poorest areas of the type.

About 75 per cent of the Miami fine sand is under cultivation, while approximately 22 per cent remains in untilled pasture land. About 2 per cent consists of sand dunes and about 1 per cent of moraines, kettle basins, and land too stony and rough to be of any value except for pasture.

The general farm crops common to the region are grown. Corn under normal conditions averages 25 bushels to the acre, oats 22 bushels, rye 12 bushels, and timothy and clover about 1 ton. Potatoes yield as high as 150 to 175 bushels per acre where given special attention, though the average is lower than this for the entire type. A crop of potatoes on the Miami fine sand is shown in Plate III, figure 1. Beans, tobacco, and cucumbers are grown to a small extent.

No definite crop rotation is in general use on this type, but one which gives good results in some sections consists of corn, followed by oats one year, then by rye for one year with clover and timothy seeded for hay. The hay is usually cut for one year and the second year the land is pastured, after which it is plowed again for corn. Where manure is available it is usually applied to the sod. Green manuring is not practiced to any extent and commercial fertilizers are seldom used. Another rotation which has given success on similar sandy soils consists of potatoes, followed by a small grain such as rye or oats, and the land seeded to clover. The first crop of clover is usually cut for hay and the second plowed under for green manuring. If sufficient manure is available the second crop of clover may be left for seed. Corn may be grown in the place of potatoes if desired. Where the soil conditions are made favorable, alfalfa may be successfully grown on this soil, though it is more difficult to secure and maintain a good stand than on a heavier soil. The production of truck crops is profitable on this type, especially near shipping points or home markets.

Owing to its loose, open structure, this soil is easily cultivated, and under good methods of farming the productiveness of the type gradually increases. The methods now followed over a large part of the type, however, are not such as tend to bring about this result. The lack of organic matter in the soil and its low water-holding capacity are best corrected by the use of stable manure and green manuring crops.

MIAMI GRAVELLY LOAM.

The Miami gravelly loam has been mapped over a total area of 45,184 acres in Fond du Lac County, Wis., and 192 acres in Auglaize County, Ohio.

The surface soil consists of a light-brown silty loam, having an average depth of about 8 inches. The subsoil to a depth of 2 or 3 feet is a brown or yellowish-brown silty clay loam, which is in most cases underlain by a heterogeneous mixture of sand, gravel, clay, and bowlders. Gravel and bowlders in varying quantities are also scattered over the surface and mixed with both soil and subsoil. In some cases the type occurs over small hills, and in such positions it is underlain at shallow depths by limestone.

The topography varies considerably, although over most of the areas it is rolling to hilly. On the steeper slopes it is necessary to leave this type in grass or in forest in order to prevent erosion. These features are shown in Plate III, figure 2. The natural drainage of the type is good, and in places where the gravel beds or the underlying rocks are near the surface it is excessive, causing the soil to be droughty in years of light rainfall.

The Miami gravelly loam is derived from glacial till, or partially reworked glacial till occurring in the form of glacial moraines, kames, and eskers. In some places where the covering of glacial material is shallow the underlying rock has contributed limestone fragments, at least to the lower subsoil.

The type was originally forested with a growth consisting chiefly of maple and oak, with some hickory.

Where the soil and subsoil have a total depth of 24 inches or more and where the surface slopes are not too steep, fair average yields are produced during seasons of normal rainfall. Where the surface covering is less than 2 feet either over the gravel or the underlying limestone, crop yields are low, and such areas are of greater value for grazing than for the production of cultivated crops. Corn, oats, barley, and mixed hay are the chief crops on the tilled areas. The rougher areas are utilized chiefly for permanent pasture and farm woodlots. Not over one-half of the type is used for crop production.

MIAMI GRAVELLY SANDY LOAM.

The Miami gravelly sandy loam has a total area of 66,944 acres in Jefferson and Waukesha Counties, Wis.

The surface soil of this type, extending to a depth of 8 to 10 inches, consists of a light-brown sandy loam. Where typically developed the soil is friable and rather loose. Varying quantities of gravel and numerous bowlders are found in the surface soil. The larger bowlders are usually removed from cultivated areas. The subsoil to a depth of about 2 feet is a reddish-brown or yellowish-brown gritty clay loam. This is generally underlain by a mass of gravel, cobblestones, and bowlders. The stony material largely consists of limestone.

The topography of the Miami gravelly sandy loam ranges from rolling to ridged and hilly. The material is derived chiefly from moraine and kame areas of glacial origin in which the underlying beds of gravel and bowlders are covered with a thin surface deposit of till. The drainage of the type is good to excessive. The steeper slopes are frequently subjected to erosion and are unfavorable for tilled crops. The more gently rolling and sloping areas, where the depth of soil and subsoil is 2 feet or more, retain sufficient moisture to mature good crops in seasons of average rainfall.

About one-half of the total area of the Miami gravelly sandy loam is under cultivation. The remainder of the type is occupied about equally by permanent pasture, consisting chiefly of bluegrass and white clover, and by farm woodlots or small tracts of forest.

The cultivated areas of the Miami gravelly sandy loam are devoted to mixed general farming, including the production of corn, oats, rye, and hay, and the raising of dairy cattle and hogs. Corn yields from 25 to 40 bushels per acre. It is not so extensively grown upon the Miami gravelly sandy loam as upon the heavier members of this series with which this type is associated. Oats constitute the chief small grain crop, giving yields of 25 to 40 bushels per acre. A small acreage of rye is grown, yielding 15 to 25 bushels per acre. Wheat and barley are grown to a small extent. The hay crop generally consists of mixed timothy and clover, and yields of about 1½ tons per acre are secured. Alfalfa is quite extensively grown on this type and is usually successful. Owing to the excellent drainage of this type and the large amount of lime carbonate in the soil, it is well adapted to alfalfa where the total depth of soil and subsoil over the underlying bowlders and gravel is 2 feet or more. This crop is not usually successful on the crests of hills and along eroded slopes where the underlying stony material is near the surface.

The Miami gravelly sandy loam is usually associated with other types of the Miami series which are somewhat better suited to the growing of corn and oats, and there is a tendency to leave this rougher and more stony land in permanent pasture. It is capable of supporting a good sod of bluegrass and white clover, and with but little attention produces good pasturage.

MIAMI SANDY LOAM.

The Miami sandy loam has thus far been encountered in only two small areas. It occupies a total of 5,440 acres in Genesee County, Mich., and a total of 1,280 acres in Fond du Lac County, Wis.

The surface soil of the Miami sandy loam has an average depth of about 10 inches, and consists of a yellowish-gray to brown sandy loam. The subsoil to a depth of 3 feet or more is a light-yellow sandy loam. This is underlain by the sandy clay or clay which constitutes the deeper till of the region. Gravel in varying quantities is found in both the soil and subsoil and is frequently scattered over the surface.

The topography of this type varies from undulating to hilly, and the natural drainage is good. During dry seasons crops suffer somewhat from drought.

Corn yields from 15 to 30 bushels an acre, with an average of about 20 bushels. Oats yield from 25 to 50 bushels, and rye averages about 15 bushels per acre. Timothy and clover are grown for hay, producing from 1 to 2 tons per acre. Irish potatoes are grown to some extent, the yields ranging from 100 to 200 bushels per acre. Small areas of beans and buckwheat are grown.

MIAMI FINE SANDY LOAM.

The Miami fine sandy loam is one of the more important and extensive members of the series. It has been mapped over a total of 281,664 acres. The principal areas thus far encountered are in the eastern and southern sections of the lower peninsula of Michigan and in the southeastern part of Wisconsin. It is probable that other areas of this type are developed in adjoining sections of these two States and in the northern part of Indiana.

The soil of the Miami fine sandy loam to an average depth of about 8 inches is a light-brown to grayish-brown medium to fine sandy loam. The color varies somewhat in different areas of the type. There is usually a tendency toward a yellowish-brown color at the surface on ridges or in other positions exposed to erosion, while the color is darker in the more nearly level areas and on the lower slopes where organic matter has accumulated to a considerable extent in the surface soil. The subsoil to an average depth of about 2 feet is a brown or yellowish-brown loam, usually containing a large amount of fine sand. This grades through a sticky sandy loam into a heavy clay loam or clay which is usually encountered at a depth of 3 feet or more. A small quantity of gravel is commonly present in the surface soil, and in greater amounts in the deeper subsoil, which also generally contains cobblestones and bowlders. In some localities bowlders are scattered over the surface of this type, although the majority of these have been removed and used in the construction of fences or the foundations of farm buildings. The gravel and other stones of smaller size, particularly in the deeper subsoil, consist largely of local limestone rock. The larger bowlders, especially those scattered over the surface, are usually crystalline rocks brought to the region through the agency of glaciation. In some instances, where the covering of glacial material is thin, limestone rock is encountered at a depth of 3 to 5 feet.

The surface configuration of the Miami fine sandy loam varies widely. The type generally occupies the rolling to hilly upland areas which mark the location of old glacial moraines. The topography ranges from rolling to ridged, with many small intervening depressions and inclosed basins between the ridges. The Miami fine sandy loam is comparatively thin over the ridges, frequently becoming thicker along the lower slopes and in the more nearly level areas. It is particularly well developed in the rolling to hilly belt which extends from the "thumb" of Michigan southwestward to the Ohio-Indiana State line. It also covers portions of the low moraines in central Michigan, from the vicinity of Lansing west and north nearly to the shore of Lake Michigan.

In south-central Wisconsin the topography of the Miami fine sandy loam is generally undulating to rolling. The type occupies low morainal ridges, undulating till plains, and some nearly level marginal areas. In extreme northern Wisconsin a large area of the type found in Marinette County is nearly level to only slightly undulating.

In general, the natural drainage of the Miami fine sandy loam is good. Where the depth of the surface sandy material is 2 feet or more, especially if the surface slopes are at all steep, there is a tendency toward droughty conditions. This is also true on the narrow crests of morainal ridges and in other places where erosion has exposed the underlying gravelly or stony material. These areas, however, are of comparatively small extent and over the greater part of the type the texture and depth are favorable to the absorption and retention of sufficient moisture for the production of the staple crops of the region. Some of the small, depressed, kettle-shaped areas of the type are rather poorly drained and are subject to the accumulation of drainage and seepage waters from higher areas of the type. These are the only areas in which the need for artificial drainage is great.

The Miami fine sandy loam has been formed by the weathering of glacial till. It is probable that the surface material has been assorted and modified to some extent through the melting of glacial ice, but in almost all instances the deeper subsoil consists of unmodified glacial till. This material has accumulated in long, irregular ranges of morainal hills, in low, undulating swells, and in the form of nearly level but somewhat irregular, dimpled till plains. The material entering into the composition of the Miami fine sandy loam consists largely of the local country rock, which in a majority of cases comprises limestone, sandstone, and shale mingled with a varying amount of the débris of crystalline rocks brought to the region during the period of glaciation. It is a common characteristic of the type that a large part of the finer gravel and even some of the coarser sandy material consists of local limestone or calcareous shale. Usually this lime-bearing material is distributed through the surface soil and upper subsoil in small quantities, becoming predominant only in the deeper subsoil. As a result, the surface soil of the Miami fine sandy loam is frequently slightly acid, while the subsoil commonly contains sufficient lime carbonate to effervesce when treated with acid.

The greater part of the Miami fine sandy loam thus far encountered in soil-survey work occurs in areas which have been used for agriculture for a long period of time, and from two-thirds to three-fourths of the area of the type in these localities is cleared and cultivated. It is only in the northern part of Wisconsin that any considerable area of the type remains to be utilized. The more rolling and thinner portions of the Miami fine sandy loam have been left in forests or permitted to grow up to scrubby timber. These and small areas which are either too steep for tillage or too poorly drained constitute the only parts of the type which are not used for farm crops.

The form of agriculture commonly practiced on the Miami fine sandy loam consists of mixed general farming, usually supplemented by dairying, hog raising, and the fattening of a few beef cattle.

Corn is the chief intertilled crop grown on this soil. It is usually planted upon sod, and applications of stable manure are commonly made. The yields range from 15 to 40 bushels per acre with a general average of about 30 bushels under ordinary seasonal conditions. The yield of corn on the deep sandy areas of the Miami fine sandy loam is usually less than on the typical areas of this soil. The Miami fine sandy loam is somewhat too porous and sandy to constitute an ideal corn soil, although the free use of stable manure and of other organic fertilizers such as clover sod and green manuring crops enable the farmers upon this type to produce fair average yields. Oats constitute the chief small-grain crop grown upon the Miami fine sandy loam. The corn stubble is usually plowed in the fall or early spring and the seeding to oats is made as early in the season as possible. Under conditions of normal rainfall oats yield from 25 to 50 bushels per acre, with an average for a long period of years of about 35 bushels. It is a common practice to seed mixed timothy and red clover or mixed red clover and alsike with the oats. In this case the land remains in hay for one or two years. The oat stubble is sometimes plowed for a succeeding crop of wheat, but this practice is no longer popular, as the yield of wheat on this soil ranges from 10 to 20 bushels per acre, with an average of not more than 14 bushels. Wheat production upon the Miami fine sandy loam is decreasing. In some localities the growing of rye has taken the

FIG. 1.—PEACH ORCHARD ON THE MIAMI FINE SANDY LÔAM IN THE MICHIGAN FRUIT BELT, NEAR GRAND RAPIDS, MICH.

FIG. 2.—AN EXTENSIVE CHERRY ORCHARD ON THE MIAMI FINE SANDY LOAM.

FIG. 1.—CONCORD GRAPES ON THE MIAMI FINE SANDY LOAM IN WESTERN MICHIGAN.

[A large apple orchard is shown in the background.]

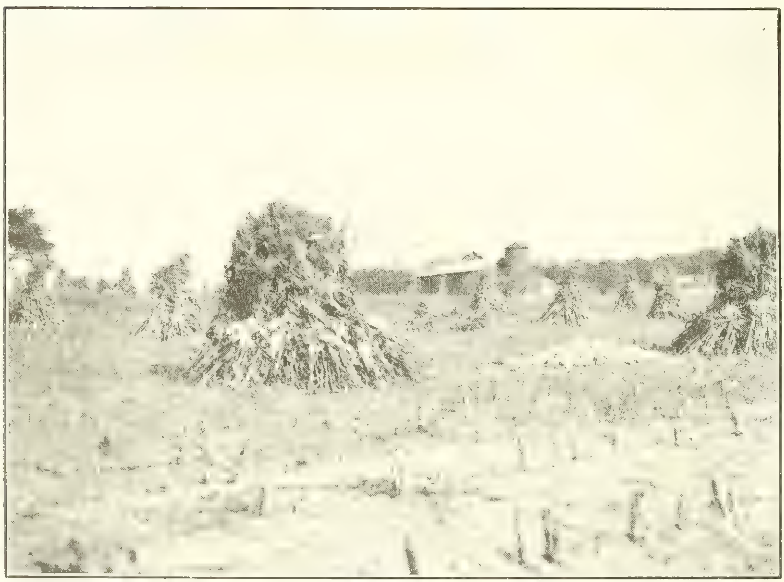

FIG. 2.—A GOOD YIELD OF WHITE DENT CORN ON MIAMI LOAM IN SOUTHERN MICHIGAN.

[A part of the corn is husked in the field and a part is cut into the silo shown in the background.]

place of wheat in the rotation, and yields of 15 to 25 bushels, with an average of about 18 bushels per acre are secured.

Barley is probably more extensively grown on the Miami fine sandy loam than any other small grain except oats. Yields of 20 to 30 bushels per acre are secured, and the grain is of excellent quality. Both rye and barley do better than wheat on this type.

The area devoted to hay production varies widely in the different sections where the Miami fine sandy loam is encountered. In southeastern Michigan probably one-third of the total area of the type produces some form of hay. Timothy and clover are most commonly seeded, especially on the dairy and stock farms. In such cases the hay is cut for one or two years, and the mowing land is then pastured for one year before being plowed for corn or some other intertilled crop. Where red clover is seeded alone the first crop is usually cut for hay and the second crop matured for seed. The yields of hay are good on all the type except the most sandy or the eroded areas. Yields of $1\frac{1}{2}$ to 2 tons of mixed hay per acre are common. The yield of clover is usually about the same. In addition to the portion of the mowing land which is annually pastured, a large part of the more rolling areas of the Miami fine sandy loam is in permanent pasture. This natural pasture consists largely of Canada bluegrass (June grass) and white clover. It usually constitutes good pasturage during the early part of the season, but has a tendency to become dry and unpalatable in mid-summer.

Beans constitute a cash crop quite generally grown on the Miami fine sandy loam in southern and southeastern Michigan. The crop is planted either on sod land or following corn. The common navy bean is most extensively grown, the yields ranging from 12 to 20 bushels per acre, with a general average of about 15 bushels. The beans are thrashed and sold to the cleaner, while the bean straw and refuse beans are commonly fed to sheep.

Early Irish potatoes constitute another special crop of importance on the Miami fine sandy loam. It is the usual practice to plant the potato crop on sod land, clover sod being preferred. The yields secured range from 60 to 150 bushels per acre, with an average of about 100 bushels. Growers who are particularly careful with the cultivation and fertilization of the crop easily exceed this average. Potatoes are commonly grown in small patches chiefly for home use, with a small surplus for market. In some parts of southern Wisconsin, however, they constitute the chief cash crop on the Miami fine sandy loam. The field shown in Plate IV, figure 1, indicates the diversity of crops grown on this soil.

Throughout southern Michigan, and to a less extent in southern Wisconsin, on nearly every farm located on or containing a considerable area of the Miami fine sandy loam a small family apple orchard is grown on this soil. Nearly all of the standard varieties are grown. The Baldwin, Duchess, Wealthy, and Wagener, are the most popular varieties in these small orchards.

The Miami fine sandy loam occurs quite extensively upon the hills and rolling ridges of the Michigan fruit belt along the eastern side of Lake Michigan. It is utilized extensively for commercial orcharding, and many varieties of apples are grown successfully. It is the best soil used for the production of the Baldwin apple. Wherever the heavier subsoil is near the surface the type is well adapted to the growing of the Spy. The other varieties grown upon this type in commercial orchards are the Wealthy, Wagener, and Shiawassee, together with subordinate varieties such as the Chenango, Maiden Blush, and Snow. The Jonathan is also grown. Apple trees on the Miami fine sandy loam are shown in Plate IV, figure 2.

Where local climatic conditions are favorable, as in the Michigan fruit belt, peaches constitute an excellent orchard crop on this type. The Elberta is the principal variety, although the Crawford and Lewis are also grown. Peach trees on this type are shown in Plate V, figure 1.

In some localities, particularly in the Traverse Bay region, the growing of cherries on the Miami fine sandy loam has become an important industry. The Montmorency, Ordinaire, Morello, and Richmond varieties are chiefly grown. A mature cherry orchard on the Miami fine sandy loam is shown in Plate V, figure 2.

In some localities grapes are successfully grown upon the Miami fine sandy loam. The Concord is the most common variety. A typical vineyard is shown in Plate VI, figure 1.

In general, the Miami fine sandy loam is well suited to orcharding and fruit growing wherever climatic conditions are favorable, and especially upon the gently rolling or slightly hilly portions of the type which are favored by good air and water drainage.

In southern and southeastern Michigan, and to a less extent in southwestern Wisconsin, dairying is an important industry on the Miami fine sandy loam. A large part of the corn grown upon this soil is cut for the silo, and this, together with the hay grown upon the farm, constitutes the chief winter feed of the cattle. The herds are usually small, averaging 10 or 12 cows to the farm, and grade animals of the different dairy breeds are commonly kept. A few farmers on this type fatten beef cattle during the winter. The raising and fattening of hogs is practiced on many of the farms. Where beans are an important crop, some sheep are kept and fed on the bean straw and other forage.

The Miami fine sandy loam constitutes a fairly good general farming soil, giving average yields of the staple crops under normal climatic conditions. It is well suited to the growing of beans and Irish potatoes. Where the climate is favorable it is used extensively for fruit production. Locally this type supports the dairy and other live-stock industries. There is a general appearance of prosperity about the farms located on this soil; the farm buildings are usually well built and in good repair, and include, in addition to the dwelling house, large barns and outhouses for the storage of hay and grains and for the housing of stock. In the dairy section of southern Michigan silos are found on practically every farm.

MIAMI LOAM.

The Miami loam has been encountered in 15 different soil surveys located in southern Michigan, northeastern Illinois, and southeastern Wisconsin. A total area of 714,614 acres of this type has been mapped. It is probable that additional areas of considerable extent will be encountered as the soil survey work is extended in this general region.

The soil of the Miami loam to an average depth of about 10 inches is a soft, friable loam of a brown or grayish-brown color. When dry the surface of a plowed field is light gray or ashy gray, while in depressions or other locations where organic matter has accumulated the color is dark gray to brown. In the more rolling areas of the type the color is usually light brown or yellowish brown. When moist the surface material is uniformly somewhat darker. Usually small quantities of gravel and in some localities a few bowlders are scattered over the surface. Some gravel is encountered in the surface soil. One phase of the type, occurring in hilly areas, is decidedly stony, but this constitutes only a small part of the area mapped.

The subsoil of the Miami loam to a depth of 2 feet or more is characteristically a yellowish-brown heavy loam or clay loam, which contains an appreciable amount of coarse sand and fine gravel and is usually somewhat gritty. This grades downward into a compact gritty clay which contains large quantities of gravel and bowlders of various sizes. The color of the deeper subsoil varies, but is usually brown or gray, or shows mottlings of these colors.

Throughout southeastern Wisconsin and northeastern Illinois a large part of the coarser sand and gravel, and many of the bowlders, consist of limestone of local derivation, and the deeper subsoil is consequently calcareous. In southern Michigan the limestone is not so abundant, but it is estimated that approximately 25 per cent of the material of the deeper subsoil is derived from calcareous rocks. In Michigan a much larger proportion of granites, schists, and other crystalline rocks has been mixed with the soil-forming material.

Field determinations indicate that the surface soil of the Miami loam is generally acid to a depth of 9 to 12 inches, even where the subsoil contains large quantities of limestone fragments.

All of the areas of the Miami loam thus far mapped are derived from the broad till plains and rolling morainic areas of glacial drift formed during the last stage of the Wisconsin ice invasion. While a large part of the material entering into the composition of the soil is derived from the local rock of each region where it is mapped, there has been added a varying amount of material brought by the glacial ice from distant localities. The crystalline rocks in the form of bowlders and gravel are of such origin, and it is probable that a large part of the finer-grained material of the soil and subsoil was similarly contributed. Consequently the Miami loam consists of a heterogenous mixture of mineral matter from a wide variety of rocks, and it is partly due to this fact that this soil is highly productive and durable under continued cultivation.

All of this derivative material was brought to its present position by the glacial ice which overspread the region. It was deposited as a thick sheet of till over the more nearly level areas, and accumulated in ridged and hilly tracts where the front of the ice stood temporarily during the retreat of the glacier. Usually such areas are marked by accumulations of bowlders at the surface and within the soil and subsoil, while occasional gravel beds and some sand occur in the deeper subsoil. Over the till plains the entire mass is a rather uniform compact, gritty, and gravelly bowlder clay.

The topography of the greater part of the Miami loam is undulating to gently rolling. There are large areas within which the surface is hilly or ridged and where the elevations rise 75 to 100 feet above the general level of the upland. These ridged areas are interspersed by large and small kettle-shaped depressions, so that the surface is decidedly irregular. Such areas are encountered where the type occurs on the morainal ridges. In southeastern Wisconsin the type is gently undulating to rolling. It occurs to some extent as long, low, gently sloping ridges, with large areas of nearly level land intervening. In general, there is sufficient slope to insure good surface drainage over the type, although in the more nearly level tracts and in local depressions the installation of tile underdrains is beneficial.

Probably over three-fourths of the total area of the Miami loam encountered in the progress of soil-survey work is under cultivation. The remainder of the type consists of broken or hilly tracts which are either forested or are utilized as permanent pasture. The type is highly esteemed for farming, and wherever the topography is favorable it is regularly cropped.

Corn is extensively grown upon the Miami loam in all of the areas mapped except in Kewaunee County, Wis., where the acreage is somewhat restricted by a normally short growing season. Elsewhere corn is the chief intertilled crop. The dent varieties are principally grown, although some flint corn is produced in the more northern localities. Under average seasonal conditions corn yields from 30 to 50 bushels per acre, depending upon the degree of care exercised in the preparation of the land and the tillage of the crop. The general average for the type is probably about 40 bushels per acre. A large part of the corn crop is harvested for the grain, although there is an increasing tendency to use it for silage. Where grown for silage the yields secured range from about 10 tons to as high as 15 or 16 tons per acre. In the dairy districts this use of the crop is becoming general. A corn field on the Miami loam is shown in Plate VI, figure 2.

The oat crop occupies the largest area among the small grains. Oats are commonly sown following corn in the rotation. The yields obtained range from 30 to 50 bushels per acre under ordinary conditions, although a production of 75 bushels per acre has been obtained. A large part of this crop is usually fed on the farm, but a portion is sold in some localities. The straw is usually fed or used for bedding. A field of oats on the Miami loam is shown in Plate VII, figure 1.

Winter wheat is grown on the Miami loam to a small extent in southern Michigan, giving yields of 12 to 30 bushels per acre, with a general average of something less than 18 bushels. The acreage is steadily decreasing. In southeastern Wisconsin barley constitutes an important crop on this soil, and yields of 25 to 30 bushels per acre are commonly obtained. It is probable that the average yield for the type is in the neighborhood of 25 bushels. Rye and buckwheat are also grown to some extent, giving fair average yields.

Hay is produced over an extensive acreage on this soil. The most common hay crop consists of a mixture of timothy and clover, although in some cases clover is seeded alone. The yields obtained range from 1½ tons to 2 tons per acre. Where clover is seeded alone it is a common practice to cut the first crop for hay and to mature seed from the second crop. In some localities in Michigan and more generally in southeastern Wisconsin the growing of alfalfa upon the Miami loam has been tried. It is a successful crop over a large part of the type, producing 2½ to 5 tons per acre. It is considered advisable to apply ground limestone at the rate of 1 or 2 tons per acre and to inoculate the alfalfa fields. It is also essential that the land be well drained in both the soil and subsoil. There has been a considerable increase in the acreage of this crop on the Miami loam during the past few years, chiefly on the dairy farms of southern Michigan and in the southeastern counties of Wisconsin.

Several special crops are grown to some extent upon the Miami loam. It is probable that the acreage of beans is largest among these crops in southern Michigan. The navy beans are grown, giving yields of 12 to 30 bushels per acre, with an average of about 20 bushels. Plate VII, figure 2, shows a good field of beans on this type. In localities near sugar factories some sugar beets are produced on the Miami loam. The yields range from 7 to 12 tons per acre, and the quality of the beets is good. The areas of the type which are well supplied with organic matter are better suited to this crop than the lighter colored areas.

Nearly every farm upon the type produces sufficient potatoes for home use, but the crop is not grown on a commercial scale to any extent. The yields range from 65 to 150 bushels per acre, the average being about 100 bushels per acre. The type is well adapted to the commercial production of this crop.

Under favorable climatic conditions the Miami loam is fairly well suited to the production of fall and winter varieties of apples. Many farms include small orchards of standard varieties which supply home needs. In southwestern Michigan the more rolling areas of the type are utilized for commercial orchards. Peaches also are grown successfully near the shore of Lake Michigan on the Miami loam. Recently grapes have been grown with success on this type in Cass County, Mich. The more rolling areas of the Miami loam, possessing good soil and air drainage, are available for orchard development, especially within the section of southwestern Michigan, where the climate is most favorable owing to the proximity of the lake.

The dairy industry constitutes an important branch of farming upon the Miami loam. In all areas where it has been encountered the chief use of the hay and grain crops is for feeding to dairy cattle. A good dairy herd is shown in Plate VIII, figure 1. The milk produced is either sold to city markets or made into butter or cheese at local factories. In some localities beef cattle are fattened from the products of this soil. Hogs are generally raised in connection with the dairy and beef cattle industries, and large numbers are marketed each year. Some sheep are kept, especially in the section where beans constitute a staple crop, the bean straw and cull beans being used for feed.

In general the farms on the Miami loam present an appearance of prosperity. The farm buildings are well built and well maintained. On the average dairy or stock-feeding farm the buildings consist of a good farm house, large dairy and stock barns, and usually one or more silos for the storage of the corn crop. Such a group is shown in Plate VIII, figure 2. The work stock is quite generally of good quality and of sufficient weight to accomplish the tillage of this soil. A large part of the farm work is done by the use of horsepower machinery.

Tile underdrainage has been installed only to a small extent in this soil. The larger part of the type is fairly well drained in its natural condition, but the more nearly level areas, especially where the subsoil is compact, heavy clay loam, are materially benefited by the use of tile. The yields of all crops are increased, while the profitable production of alfalfa and even of red clover depends to a considerable degree upon the use of tile drains to improve the drainage of the subsoil.

The crop rotations upon the different areas of the Miami loam vary considerably. The general practice is to plow sod land for the growing of corn. The next year the land is seeded to oats. This crop is usually followed either by wheat or barley, and a seeding to mixed timothy and red clover or to clover alone is made with the second grain crop. The land is allowed to remain in hay for two or more years. It may be pastured the last year in sod. Potatoes, beans, sugar beets, or other intertilled crops are usually planted on sod land, although the local practice varies somewhat.

Little commercial fertilizer is used upon the Miami loam. The cheaper grades, rather high in phosphoric acid, are used for wheat to some extent. The stable manure produced upon the farm is commonly applied to the land to be plowed for corn. Some farmers use the manure as a top dressing on the grass land the second year after seeding. Practically no use of green manuring crops is made, and the stable manure and the sod, which is turned under for the corn crop, are depended upon for the maintenance of organic matter in this soil. A field in which clover sod is being plowed under is shown in Plate IX, figure 1. It is probable that considerable improvement in the condition of the more sloping areas of this type could be effected through the use of winter cover crops, to be turned under to increase the organic matter in the surface soil.

Although the subsoil of the Miami loam is generally well supplied with lime, it has been found profitable to apply lime to the surface soil when seeding to clover or alfalfa. Usually 1,000 to 1,500 pounds of quicklime or 1 to 1½ tons of ground limestone per acre is sufficient to put the surface soil in good condition for the growing of the leguminous crops.

Practically all of the Miami loam which is not too steep or stony for cultivation is utilized for cropping. The type may be classed as a very good general farming soil, upon which corn, oats, wheat, barley, and hay produce yields in excess of the general average for the different regions in which the type is found. Special crops are grown to some extent in different localities. Of these beans and sugar beets are most important, while nearly every farm on the type annually produces enough potatoes for the home supply. This crop might be more extensively grown to advantage. Rye and buckwheat produce fair yields, but are not grown extensively.

The crops produced upon the Miami loam are largely fed to dairy and beef cattle and to hogs and sheep. The wheat and some of the oats and barley are sold. The sale of surplus hay is an important source of income in some localities. The farms are generally well improved, well stocked, and maintained in a good state of productiveness. Under favorable conditions of climate and drainage it is possible to utilize this soil for the growing of the standard varieties of apples and for the production of peaches and grapes.

MIAMI SILT LOAM.

The Miami silt loam is an important and extensive soil type which has been encountered chiefly in central Indiana, northeastern Illinois, and southeastern Wisconsin. It has been mapped in 11 soil survey areas, occupying a total of 1,230,116 acres. It is known to occur in areas of considerable size in adjoining regions.

The different areas of the Miami silt loam vary somewhat in color, topography, and drainage. Some of these variations are of sufficient effect upon the cropping value of the soil and upon the methods by which it may best be tilled and managed to warrant the separation of two phases of the type, in addition to its normal development. The typical soil is the most extensive and important, but the flat phase and the deep phase occupy large areas.

The Miami silt loam consists normally of a dark-gray or light-brown, friable silty loam having an average depth of about 10 inches. The surface soil is usually somewhat deeper over level or depressed areas and shallower on steep slopes and over the crests of ridges. When moist the surface color is almost uniformly a grayish or yellowish brown, but when thoroughly dry it becomes a light or ashy gray.

The immediate subsoil to a depth varying from 20 to 30 inches is a yellow or yellowish-brown silty clay loam. This is underlain by a yellowish-brown or brown, gritty or sandy clay, usually containing an appreciable amount of coarse sand, gravel, and bowlders. As a rule this stony material consists chiefly of limestone, although crystalline erratics of various kinds form a part of the coarser grained material.

A scattering of gravel and some cobblestones are encountered on the ridges and knolls occurring within the Miami silt loam, and in some

FIG. 1.—OATS ON MIAMI LOAM NEAR WAUKESHA, WIS.

[Note the rolling surface of the country.]

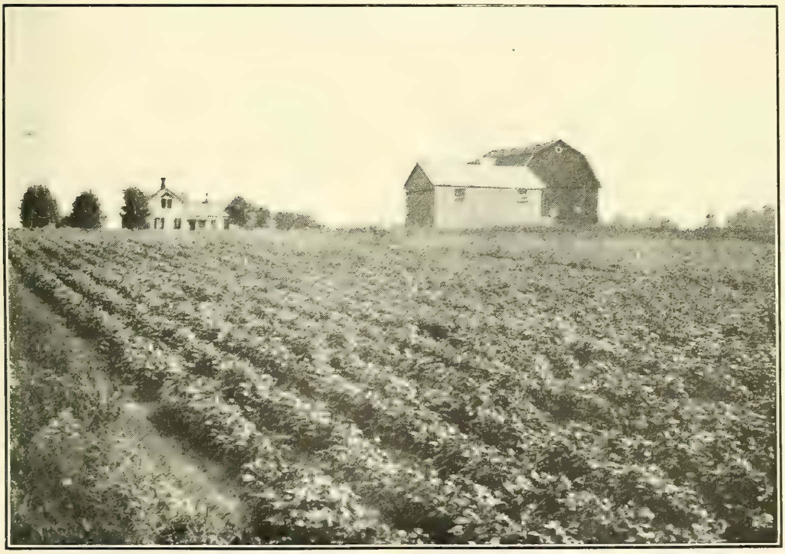

FIG. 2.—BEANS ON THE MIAMI LOAM IN GENESEE COUNTY, MICH.

[The farm buildings are typical of the region.]

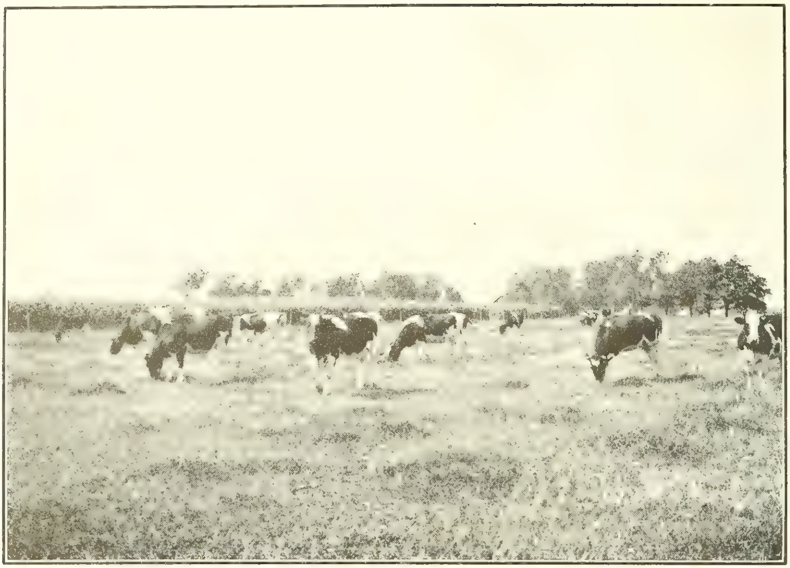

FIG. 1.—A PUREBRED DAIRY HERD ON THE MIAMI LOAM IN SOUTHERN WISCONSIN.

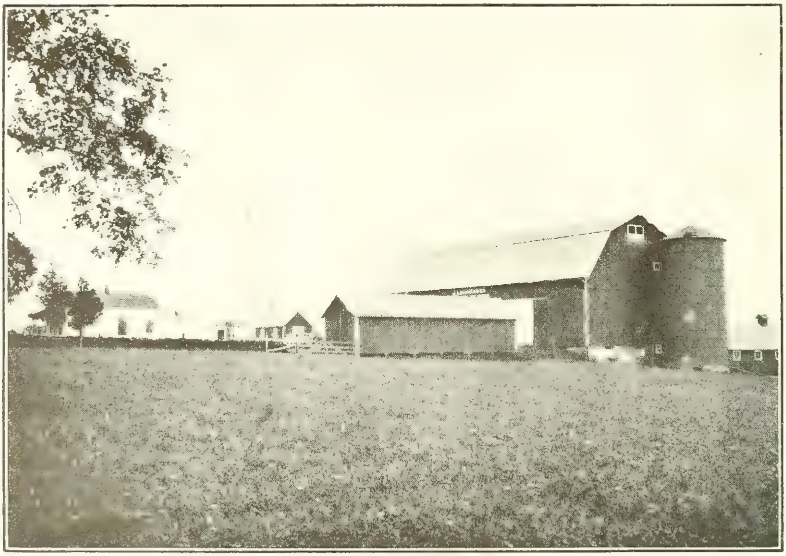

FIG. 2.—CHARACTERISTIC FARM BUILDINGS ON A DAIRY FARM IN SOUTHERN MICHIGAN, NEAR FLINT, GENESEE COUNTY.

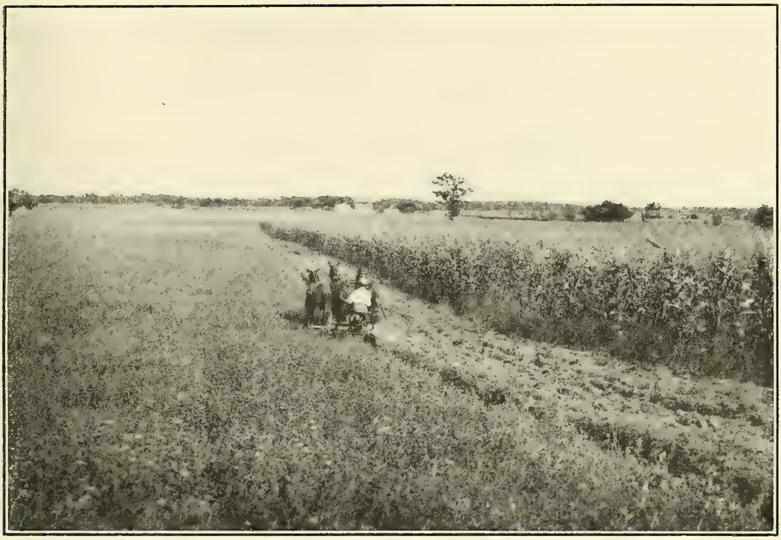

FIG. 1.—PLOWING UNDER SECOND GROWTH OF CLOVER TO ADD ORGANIC MATTER TO THE SOIL, SOUTHERN WISCONSIN.

FIG. 2.—UNDULATING TILL PLAINS OCCUPIED BY MIAMI SILT LOAM, DEEP PHASE, IN JEFFERSON COUNTY, WIS.

FIG. 1.—HERD OF BEEF CATTLE ON MIAMI SILT LOAM.

FIG. 2.—REPRESENTATIVE FIELD OF CORN ON MIAMI SILT LOAM IN SOUTHERN WISCONSIN.

localities bowlders were numerous until removed from the fields and used for the construction of foundations of farm buildings. The stony areas are not usually extensive. On steep slopes within the type erosion has sometimes exposed the deeper subsoil, and gravelly and stony patches are found.

The topography of the greater part of the Miami silt loam is gently rolling to ridged and hilly. The type also occupies smaller tracts which are merely undulating or nearly level. The range in elevation within the limits of the type is greater in the southeastern part of Wisconsin than elsewhere, differences in elevation of 100 to 200 feet being encountered in the majority of the areas, with an extreme range of 500 feet or more. The type in this region occupies the tops and slopes of ridges, and the gently rolling or undulating till plains between the more pronounced glacial ridges. The undulating surface of such areas of the type is shown in Plate IX, figure 2. In central Indiana the differences in elevation are not so great. The elevation ranges from 50 to 150 feet, and a larger part of the type is marked by a low, undulating surface whose extreme elevations are not more than 25 to 50 feet above the general level. It is only along the courses of the larger streams, where erosion has modified the original surface, that steep slopes or considerable differences in elevation are found in this section. The greater part of all the areas mapped is best described as gently rolling or undulating, with a smaller part either nearly level or distinctly ridged.

Because of this moderate relief and of the generally sloping surface of the Miami silt loam it is commonly well drained in its natural condition. The presence of the gravelly and stony deeper subsoil also aids in subsurface drainage of the type. It was usually sufficiently well drained and elevated to be selected by the early settlers in the different regions. In some localities the low ridges included within areas of this soil were the only available sites for homes in pioneer days.

The entire type was originally forested, mainly with sugar maple, beech, hickory, oak of several species, some walnut, and a small amount of elm and ash. Nearly all of this original growth has been removed, and only the steeper and more hilly or stony areas remain in forest or farm woodlots. In some sections more than 95 per cent of the type is under cultivation, while it is probable that 80 per cent of the total area of this soil is used for some form of crop production. The remainder consists of pasture land and woodlots.

In all the regions in which it is developed the Miami silt loam has been esteemed as a productive general farming soil since its first occupation. In its forested condition a fair amount of organic matter accumulated in the surface soil, and it was usually well drained.

The timber growth furnished materials for the construction of farm buildings. The associated prairie lands were usually either poorly drained or covered with a tough sod which was difficult to break and convert into tilled fields. Wheat and corn were the crops first produced, and these are still important crops upon this soil. At one time it was found that the yields of wheat were decreasing, because of the practice of continuous cropping to this grain, and, probably, because of the exhaustion of a part of the original supply of organic matter in the surface soil. Definite crop rotations were introduced, and corn assumed considerable importance. At present a decidedly diversified type of general farming is commonly practiced on the Miami silt loam, while in southeastern Wisconsin the dairy industry occupies a prominent place upon it. In Indiana dairying is usually subordinate to the growing of grain crops, and to the fattening of beef cattle and the production of pork. A good herd of beef cattle is shown in Plate X, figure 1.

Corn is produced on practically all areas of the type. The yellow dent varieties are generally grown, although the white dent corn is also popular. Little flint corn is grown, as the growing season is sufficiently long to permit the production of the heavier yielding dent varieties. A representative field of corn on the Miami silt loam is shown in Plate X, figure 2.

The greater part of the corn harvested from this type is husked and shelled for the grain. Yields vary in different seasons and with different methods of cultivation, but a production of 40 to 60 bushels of corn per acre is not unusual, while yields of as much as 75 bushels per acre are obtained under favorable circumstances. The general average production is probably about 40 bushels per acre. A large part of the corn crop is annually cut into the silo, especially in the dairy district of southeastern Wisconsin, and upon those farms in Indiana where the fattening of beef cattle forms a part of the farm system. This is shown in plate XI, figure 1. The practice is increasing in popularity. Yields of silage range from 10 to 15 tons per acre, with an average of about 12 tons. All the better drained areas of the type which are fairly well supplied with organic matter produce good average yields of corn, although the yields obtained are usually below those secured upon the "black land" of the Clyde series associated with the Miami silt loam in many localities. In general, the largest yields of corn are secured where a regular rotation of crops is observed and where the corn is planted upon a clover sod or upon a timothy and clover sod. On the dairy and stock farms, where such rotations are practiced, and where a considerable amount of stable manure is also used upon the corn land, the yields of corn are above the general average for the locality. The tile underdrainage of this type in the more nearly level areas increases the certainty of securing a good stand of corn and improves the yields. In many cases corn is planted for two or three years in succession upon the same field, but it is generally recognized that better results are obtained where it is only grown for a single year upon sod ground and followed in regular rotation by small grains and grass.

Among the small grains oats are most extensively grown, particularly in the more northern localities. The crop is sown upon corn-stubble land. Such land is usually plowed for the oat crop, but may be prepared by disk harrowing without plowing. The yields obtained range from 35 or 40 bushels to as high as 65 bushels per acre. The general average for the type is probably about 40 bushels per acre. A large part of the grain is fed on the farm, and the straw is used for feed and bedding. In some localities a small part of the grain is marketed.

Winter wheat also occupies an important acreage upon the Miami silt loam, although the area annually sown to this crop is decreasing. Yields range from 12 to 30 bushels, with a general average of about 18 bushels per acre. It is the usual practice to plow the oat-stubble land for wheat and to seed timothy with the wheat in the fall. In the spring an additional seeding of clover is made upon the wheat.

The growing of hay crops is important on the Miami silt loam. The acreage devoted to mixed timothy and clover probably exceeds that of any other single crop on the type. The yields secured are excellent, ranging from 1½ tons to as high as 2½ tons per acre. A smaller acreage of clover alone is grown, giving about the same yields. Usually the mixed seeding is cut for two or more years, and a crop of timothy seed is sometimes secured from the last cutting or the meadows are grazed before being broken for corn. The second crop of clover is often matured for seed. Timothy yields 7 or 8 bushels and clover 1 to 2 bushels of seed per acre.

In some parts of southeastern Wisconsin alfalfa has been successfully grown on the better drained areas of this soil. The yields range from 2½ to 5 tons per acre in three cuttings. The acreage of alfalfa upon this and associated soils of the Miami series is steadily increasing in this region. It has been found that inoculation of the soil is essential to success with alfalfa, and it is considered advisable to use ground limestone rock at the rate of a ton or more per acre where alfalfa is to be seeded. Even where there is a considerable amount of limestone gravel in the deeper subsoil the use of lime to sweeten the surface soil is generally necessary.

Some of the more rolling and rougher areas of the Miami silt loam, where the surface is too uneven for cultivation, afford excellent natural pasturage in which Kentucky bluegrass usually predominates. These pastures are maintained permanently in sod.

Potatoes are nowhere grown to any extent as a commercial crop on the Miami silt loam. Nearly every farm annually produces a small acreage for home use. The yields range from 75 to 150 bushels per acre, and it is probable that improved methods of fertilization and cultivation would make the crop a commercial possibility.

Beans are grown to a limited extent in some localities in southeastern Wisconsin, giving an average yield of about 20 bushels per acre. Sugar beets also are grown in this section and the yields range from 10 to 15 tons per acre. The production of tobacco is chiefly confined to the deep phase of the type. A field is shown in Plate XI, figure 2.

Many of the farms on the Miami silt loam include small orchards for the home supply of fruit. Where orchard locations are well selected upon rolling or hilly ground, giving good air and water drainage, the winter varieties of apples are successfully grown. Cherries and plums do well in the home orchards. It is hardly advisable to attempt commercial orcharding on any large scale on this soil.

The usual crop rotation on the Miami silt loam in Indiana consists of corn grown for one or more years, followed by oats for one year; then winter wheat is grown for one year, and a seeding to mixed timothy and red clover or to clover alone is made on the wheat, and the land is devoted to hay for one year. The field may be pastured for one year or the sod turned under to return to corn. There is a constant tendency to grow as large an acreage of corn as possible and to reduce the acreage in wheat. It is claimed that the yields of winter wheat are not as large as in former years and the production is such that other crops prove more profitable upon this high-priced land. In southeastern Wisconsin, barley has almost completely displaced wheat and wheat growing has been practically discontinued. The usual crop rotation in this section consists of corn for one year, followed by oats one year and then barley, or the barley may be omitted. In either case a seeding to mixed timothy and clover is made with the small-grain crop and the land is usually kept in hay for two or more years. The sod is then plowed for corn.

In the dairy regions stable manure is the chief fertilizer used on the Miami silt loam. It is usually applied to the corn ground either on the sod before turning under or on the plowed land to be harrowed in before the planting of the crop. In some cases a commercial fertilizer is used with the small grain crop. In Indiana the use of commercial fertilizer is more general. It is applied at the rate of 150 to 250 pounds per acre on the corn, and a like amount is frequently applied with the wheat. One of the chief needs of this soil is the restoration of organic matter, and the more general use of stable manure is to be recommended. Where possible it is also advisable to use some of the leguminous crops, such as clover, for green manuring. Regularly plowing under a good clover sod in the rotation is a fairly satisfactory means of maintaining the organic-matter supply in the surface soil.

The Miami silt loam is used for somewhat different types of farming in the various areas where it has been mapped. Its chief use in southeastern Wisconsin is for mixed general farming, with the dairy industry as an important part of the system. Many excellent herds of registered and grade cows of the leading dairy breeds are maintained. The crops most successfully grown—corn, clover, alfalfa, and oats and barley—are all suitable for dairy feeding. The dairy farms are usually well improved with modern farmhouses, large dairy barns, silos, and necessary outbuildings. The fertility of these farms is well maintained by the use of stable manure, and the crop yields are quite generally satisfactory. In Indiana a much larger proportion of the type is used for grain farming, supplemented in many instances by the fattening of beef cattle and the growing of hogs. Where beef cattle are fattened the improvements are about the same as upon dairy farms. Both systems of agriculture are well suited to this soil. Where the production and sale of grain is made the chief object, the buildings are not usually so complete and the crop-producing power of the land is not so high. This probably arises to a considerable degree from the lack of stable manure, the use of which is of great benefit to this soil.

The majority of the farms on the Miami silt loam are in good condition and show evidences of a prosperous state of agriculture.

Flat phase.—The flat phase of the Miami silt loam is almost exclusively confined to the areas surveyed in central and west-central Indiana. These areas include Boone, Hamilton, and Tipton Counties, where this phase predominates, and portions of Montgomery and Tippecanoe Counties, where it is subordinate in area to the normal or rolling phase of the type.

In this region the Miami silt loam, flat phase, is a light-colored upland soil, locally known as "clay land" to distinguish it from the black silty clay loam soils with which it is commonly associated. It occupies from 40 to 60 per cent of the total area in this section.

The surface soil to an average depth of 10 inches is a light-gray silt which varies in color from ashy gray when dry to a pronounced brownish-gray under normal moisture conditions. It is a soft, flourlike material which contains few coarse particles and which is usually rather deficient in organic matter.

The subsoil to a depth of 25 to 30 inches is a stiff silty clay loam or clay. The upper part of the subsoil is frequently mottled yellow and gray, and may be somewhat friable. With increasing depth it becomes more compact and claylike. The lower part of the 3-foot section is usually a brownish clay or clay loam containing considerable sand and gravel. At greater depths the material becomes distinctly gravelly and sandy, and numerous bowlders are encountered. The flat phase grades into the Clyde silty clay loam in depressions where there has been a considerable accumulation of organic matter, and into the normal or rolling phase of the Miami silt loam where the topography becomes somewhat more rolling and the covering of silt over the underlying sandy and stony clay is of less depth. This phase of the type is practically stone free at the surface.

The surface of practically all of this phase is only very gently undulating, while considerable tracts are nearly level. Some small areas of low relief are found within the phase. The depressed and nearly level areas are usually rather poorly drained, and only the more elevated areas lying along the crests of low swells have fair to good natural drainage. The greater part of the phase would be materially benefited by the installation of tile underdrainage.

The flat phase of the Miami silt loam originally supported a mixed growth of hardwood timber in which beech predominated. It came to be known as "beech land," in distinction from the more rolling phase of this type, which was known as "sugar-tree land" because of the greater abundance of sugar maple. With the exception of small woodlots, the phase has been cleared, and probably 90 per cent of its area is under cultivation.

Corn is extensively grown, giving yields which average somewhat below 40 bushels per acre. During exceptionally wet years the yield is far below this, and extreme drought also exerts a very unfavorable influence upon the yield. This phase is not so well suited to corn production as the more rolling part of the type, and the yields are frequently below the average for the region.

Wheat is commonly grown and constitutes the chief small-grain crop on this phase of the type. The yields range from 12 to 20 bushels per acre, with an average of about 15 bushels. Oats are also grown, and in years of abundant rainfall give excellent results. The yields range from 30 to 50 bushels per acre, with an average of approximately 35 bushels.

Timothy and clover constitute the chief hay crops. Timothy is well suited to this soil, while red clover is not so successfully grown as on the more rolling phase.

Tomatoes for canning are grown to some extent, and potatoes and garden vegetables are produced for home consumption.

Deep phase.—The deep phase of the Miami silt loam has been mapped extensively in south-central Wisconsin, where it occurs in Dane, Columbia, and Fond du Lac Counties.

The surface soil of this phase extends to an average depth of 10 inches and consists of a light-brown friable silt loam. The color of the surface soil when dry is ashy gray. The subsoil is a yellow silt loam, which becomes heavier with increased depth, grading into a yellowish-brown silty clay loam at 20 to 24 inches. This material usually extends to a depth of 3 to 6 feet, where it is underlain by glacial till consisting of a mixture of sand, silt, clay, and gravel. There is a sharp line of demarcation between the silty material forming the surface soil and the immediate subsoil and between the subsoil and the deeper glacial till. Stone and gravel are almost entirely lacking in the surface 2 or 3 feet, but are numerous in the deeper subsoil. A large part of this stony material consists of limestone. In some localities the underlying rock is encountered at a depth of 2 feet or less. In general stony areas are of small extent within this phase.

The topography of the Miami silt loam, deep phase, is gently rolling or undulating, and the surface slopes are generally smooth and gentle. Differences of elevation of 100 feet or more occur within the phase, and there are some distinctly hilly areas of rather small extent. The phase occupies the tops and sides of the low, rolling hills and the more gently undulating intervening plains. In a small area west of the Wisconsin River, in Columbia County, this phase is distinctly hilly, with differences in elevation of 500 or 600 feet. In general the surface drainage of the phase is good, although small depressed areas are in need of tile underdrainage.

The deep phase of the Miami silt loam is the most productive part of the type. Practically all of it is under cultivation, all the general farm crops of the region being produced. Corn is the leading crop, and average yields of 40 bushels per acre are secured. Yields of as much as 70 bushels have been obtained. Oats occupy the largest acreage of any small-grain crop and give yields of 35 to 70 bushels, with an average of 40 bushels per acre. Barley also is grown, producing 20 to 45 bushels per acre. Some winter wheat is grown, giving acreage yields of 15 to 30 bushels. The acreage of both wheat and barley is said to be decreasing. The thrashing of small grains on a farm located on this phase in southern Wisconsin is shown in Plate XII, figure 1.

A large area of this phase is seeded to mixed timothy and clover, and yields of 1 to 2½ tons of hay per acre are secured. In some localities difficulty has been experienced in securing a stand of clover, and timothy is being seeded alone.

In Columbia County, Wis., several special crops are grown to advantage on this phase. Green peas for canning produce 1,800 to 2,000 pounds per acre. Where allowed to mature, a yield of about 15 bushels per acre of seed peas is secured. Beans also are grown, giving an average yield of about 20 bushels per acre. Some sugar beets are planted, producing from 10 to 15 tons per acre of beets of good quality. In southern Wisconsin the binder type of tobacco is grown on this phase, giving yields of 1,000 to 1,500 pounds per acre. Potatoes are grown chiefly for home use.

It is a common practice on the deep phase of the Miami silt loam to use a rotation consisting of corn, followed by a small grain, either oats, barley, or wheat, then seeding to timothy and clover. The small grain is sown either one or two years. Hay is usually cut for one or two years, and the land is sometimes pastured for an additional year. The field is then manured and again plowed for corn.

General farming, consisting mainly of the production of hay and grain, and dairying are the dominant types of agriculture practiced on this phase. Where local market facilities are good the growing of special crops, such as sugar beets, peas, beans, and tobacco, is practiced in conjunction with the production of the more common farm crops.

The farms on the deep phase of the Miami silt loam are commonly well equipped with buildings, work stock, and machinery, and indicate a generally prosperous condition. While farming conditions are fairly good, the average yields produced upon this phase are somewhat below the natural capacity of such a soil. The rather general lack of organic matter in the surface soil should be corrected by the use of stable manure and the plowing under of green manuring crops. The use of ground limestone at the rate of 1 ton or more per acre would assist in securing a better stand of clover, and alfalfa can be grown successfully only where such an application is made.

The Miami silt loam, in its different phases, is a fairly good general farming soil, suited to the growing of small grains and grass and giving fair to good results with corn. The flat phase is rather poorly drained and yields are generally low in years of excessive rainfall. It is also difficult to secure good yields under drought conditions because of the tendency toward the baking of the surface soil. Underdrainage and the incorporation of large quantities of organic matter will tend to remedy this condition.

The normal phase of the type is usually sufficiently rolling to have fair natural drainage, although some nearly level areas and many small depressed areas are in need of tiling. The rolling areas of this phase are adapted to a wide range of farm crops and are also better suited than any other part of the type to the growing of home orchards of winter apples and other fruits. The deep phase of the type is generally well drained and somewhat superior to other parts of the type, especially for corn production.

Although the deeper subsoil of all parts of the type is usually well supplied with limestone, it has been found that the surface soil is decidedly benefited by the application of ground limestone at the rate of 1 ton or more per acre. The limestone is helpful in securing better stands of clover and decidedly essential to the growing of alfalfa.

Hay, oats, and corn constitute the crops most extensively grown, while winter wheat and barley are also important. In the more southern areas hay and grain production and the fattening of beef cattle are the dominant industries, while in Wisconsin the growing of general farm crops and dairying predominate.

THE MIAMI CLAY LOAM.

The Miami clay loam is most extensively developed in Indiana, Michigan, and Ohio, though small areas are found in Wisconsin and Iowa. A total of 2,342,410 acres of this type has been mapped in the five States in which it has been encountered. The soil surveys already completed, however, indicate that the Miami clay loam constitutes one of the dominant soils of central and western Ohio, northern Indiana, and southern Michigan. From all of the localities in which this type has been recognized its area extends into bordering counties, indicating the existence of millions of acres of the type within the general region in which the Miami series is developed.[1]

The surface soil of the Miami clay loam is a brown, yellow, or gray silty loam. The depth of this surface soil is rarely less than 6 inches, except in small areas on steep slopes, where erosion has been active. It is generally more than 10 inches in depth, constituting an unusually deep surface soil. This material is frequently underlain by a yellow or brown heavy silty loam which extends to a depth of about 2 feet, and this in turn is underlain by a brown, yellow, gray, or drab, frequently mottled silty clay loam or heavy clay. At a depth varying from 2 feet to 5 or 6 feet the typical blue or drab bowlder clay, with the characteristic glacial pebbles and bowlders, is almost universally developed. Only on slopes and in other localities where the surface soil and subsoil are unusually shallow is the consolidated underlying rock encountered. Usually the depth of the glacial till over bedrock is from 40 to 250 feet. The Miami clay loam is derived from deep, complex, mechanically broken soil-making material of glacial origin. The soil itself has been slowly formed through the processes of weathering of the surface portion of this material. The glacial origin of the soil, insuring the commingling of earthy material from a great variety of sources, the great depth of the soil-making material, and the compact nature of the mass which resists exces-

[1] It is probable that some areas of Miami silt loam have been included with areas of the Miami clay loam in some of the earlier soil surveys in Ohio and Indiana.

sive erosion all tend to form a soil of medium to good fertility and of a most durable quality under even fair conditions of agricultural use.

In many regions where the Miami clay loam is encountered, scattered bowlders and small stones are found locally over the surface of the type, and in increasing quantities in the deeper subsoil and underlying till. In some small areas this accumulation of stone may be sufficient to interfere somewhat with cultivation. In such cases the stone is usually gathered from the field and used in the construction of fences or buildings. In general, however, the surface soil is fairly free from any large masses of rock or extensive accumulations of stone and gravel. The larger rock masses associated with the Miami clay loam roughly indicate the character of the finer grained soil-forming material. The bowlders, stone, and gravel comprise fragments of practically every known variety of igneous, metamorphic, and sedimentary rock occurring within the area occupied by the type or within the extensive tracts to the north from which the glacial ice passed southward to deposit its load. Granites, gneisses, schists, sandstone, limestone, and quartzite are all found among the glacial bowlders and pebbles. The softer rocks, such as shale, have usually been so finely ground by glacial action as to prevent identification in the majority of the areas. Usually a large part of the rock fragments in the deeper subsoil consists of limestone.

Considering the wide extent of territory over which the Miami clay loam is developed and its derivation from ice-laid materials, the surface configuration of the type is unusually uniform, or at least varies within reasonably narrow limits. In general, the surface of the type is gently undulating or slightly rolling with local low, rounded hills or steep-sided knobs in areas which include distinct glacial moraines. The only other hilly or steeply sloping areas of the Miami clay loam are those found where postglacial streams have cut deeply below the glacial upland surface, and have extended their minor branches through the upland areas occupied by the Miami clay loam.

The altitudes at which this type is developed vary from approximately 600 feet above tide level in the vicinity of Lakes Erie and Michigan to altitudes of a little more than 1,300 feet in southwestern Ohio and southeastern Indiana. These differences in altitude arise chiefly from differences in the elevation of the rock floor over which the glacial materials were laid down. The rolling surface of the soil type itself slopes gently upward from its lower elevations to the highest altitudes attained near the southern boundary of glaciation.

There is considerable variation in the natural drainage of the Miami clay loam. The more nearly level areas, especially those somewhat remote from lines of pronounced stream drainage, are usually wet and poorly drained. This is due both to the level surface of the soil and to the great depth of the massive, stiff glacial clay from which the soil itself has been formed. Thus, both the surface drainage and the internal soil and subsoil drainage are deficient over such areas. In the more rolling portions, such as comprise extensive areas in southern Michigan, west-central Ohio, and eastern Indiana, the drainage of the type is unusually good, and for this reason it was frequently selected for settlement in pioneer days. In no case is the drainage of the Miami clay loam excessive.

Erosion constitutes a soil problem only in the steeper sloping areas of the Miami clay loam where the land breaks sharply from the general upland level down to the valley of some deeply incised stream course. Such areas are usually maintained in forests or woodlots, or at most are occupied for permanent pasture, so that the erosion problem upon this type is scarcely worthy of serious consideration.

The organic-matter content of the surface soil varies with the slope of the type and with its condition of natural drainage. In lower lying hollows and at the lower altitudes there is a tendency toward the accumulation of organic matter, resulting in the darker brown to black coloring of the surface soil and frequently in a more mealy and friable structure. In such locations the material grades toward the soils of the Clyde series, the silty clay member of which is generally associated with this type. Over the greater part of the area of the Miami clay loam the surface soil is brown or gray in color. In such areas a moderate amount of organic matter is present within the surface soil and the best conditions for crop production are thus indicated. On steep slopes, where erosion has been active, the surface soil is frequently absent and the brown, pale-yellow, ash-colored or blue subsoil material is exposed. Very little organic matter is present in the surface material of such areas, and the incorporation of organic manures is necessary. In general, the organic-matter content of the Miami clay loam, particularly in forested regions, is about the average for upland glacial soils.

All areas of the Miami clay loam mapped lie within the cool temperate region of central United States, which is supplied with abundant but not excessive rainfall. This fact, coupled with the fine texture and dense structure of the soil material itself, restricts the use of the soil to the production of general farm crops, particularly the small grains and grasses. Thus the Miami clay loam is a general farming soil rather than a special-purpose soil, and its crop adaptations are such as to encourage the production of small grains.

The increased yields of the general farm crops secured upon such tracts of this type as have been adequately tile drained indicate that this is one of the most effective methods of improving the Miami clay loam. Particularly where the surface features are level to gently undulating, where farm lands are remote from deeply cut stream trenches, or where depressions exist over the surface of the type, the installation of tile drains is of fundamental importance in the proper utilization of this soil. The contrasts in crop yields between properly drained and poorly drained areas of the type, whether this drainage is accomplished naturally or through the installation of tile, are marked. With adequate drainage the Miami clay loam ranks high, not only for the production of winter wheat, oats, and grass, but also as a corn-producing soil. On the other hand, where drainage is deficient the production of corn and of winter wheat is practically impossible, or the yields secured are too small to justify the growing of these crops. There are areas of the Miami clay loam, particularly in the more eastern States, which, because of poor drainage, have not been cleared and brought under cultivation until within the last half century, and then only through the construction of open ditches and the installation of systems of tile drainage. Flat areas which have not been so treated still produce small crop yields where they are farmed and do not possess that wide range of cropping possibility which is essential to a well-balanced system of general farming. The cost of tile draining a stiff, impervious soil of this character, and especially one where the deeper subsoil is likely to contain considerable masses of stone or even large bowlders, is rather high, ranging from $20 to $30 an acre for the complete drainage of entire fields. Nevertheless, when this is considered as an investment, adding to the permanent value of the land, it is usually justified, not only by the increased yields secured, but also by the rapidly increasing value of the land itself. Tile drains to be effective upon the Miami clay loam should have considerable internal diameter and adequate fall along the ditch line, and should be placed at rather frequent intervals and at an average depth of not less than 3 feet. These requirements give rise to the rather high cost of adequate underdrainage of the type.

The frequent incorporation of a reasonable amount of organic matter in the surface soil is also requisite to maintain or to increase the efficiency of the Miami clay loam. The prevailing systems of farming upon the type are fairly adequate for this purpose, in that grass constitutes an important crop in the regular rotation practiced over practically the entire area of this soil. The plowing under of the sod in the preparation of the land for corn or other hoed crops assists in the maintenance of organic matter in the soil, while the keeping of beef cattle and of dairy cows upon the areas of this type renders the application of stable manure possible over a large part of the arable acreage each year. The better farmers throughout the section occupied by the Miami clay loam practice these methods of organic-matter restoration and are well repaid by crop yields being maintained and even increased.

In connection with the production of the grass crops, particularly the clovers, the application of lime to this dense, compact soil results in increased yields wherever it is properly practiced. Either finely ground limestone rock or the burned stone lime may be used for this purpose. Where the powdered limestone is used, considerably larger applications are required than in the case of the quick lime. In the latter case applications of 1,500 to 2,000 pounds per acre result in marked increases in the yields of clover hay. At least double this quantity of ground limestone is necessary in order to secure the same results.

Another method for securing improvement in the crop yields of the Miami clay loam consists of the maintenance of the best tilth possible in the surface soil. The fine texture of the surface soil gives rise to a tendency toward clodding and baking unless the land is handled when the moisture conditions both of the surface soil and subsoil are particularly favorable. Plowing should not be attempted either when the soil is thoroughly baked and hardened or when it is wet and soft. In the former case large clods are formed which are very difficult to break down into a favorable condition by any subsequent tillage operations. In the latter case both the surface soil and the subsoil at plow depth are likely to become puddled and to form a "hardpan" or other physical condition unfavorable to the processes of root growth. A little care in the plowing of this land when it is in the condition of optimum moisture content will usually obviate both of these difficulties. It should be held in mind, moreover, by every owner of land of this character that the soil resources locked up in the baked and hardened clods are absolutely unavailable for the use of the growing crops, besides constituting a danger in the cultivation of the intertilled crops through the breaking down of the young plants. Thorough harrowing, preferably with the disk harrow, will generally serve to break up the surface clods, and the use of some such tillage implement is necessary in the proper preparation of the land.

There are few special crops which are suited to production upon the Miami clay loam, and the best types of agriculture conducted upon this soil are those embodying the production of grain and grass and the utilization of these for feeding dairy cattle and other stock. In the more rolling areas, especially where the low hills of the morainal belt are found, apple orcharding may be undertaken on a small scale. Even in such areas the heavy texture of the soil and the dense subsoil limit the varieties which may be produced. Pears constitute the only orchard fruit other than apples that is well suited to a soil of such heavy texture.

Tobacco is produced on the Miami clay loam in southern and southwestern Ohio in areas which are particularly well drained, are heavily manured and fertilized, and which have been brought into good mechanical condition by careful tillage. These constitute practically the only special crops which are suited to production upon the Miami clay loam, both because of its textural peculiarities and because of the climate.

The Miami clay loam, locally known as "maple land" or "walnut land," from the dominant species of its native hardwood trees, was selected for clearing and settlement early in the pioneer days in Michigan, Ohio, and Indiana. The type supported a heavy growth of a great variety of hardwoods. Throughout Ohio it was forested with oak, maple, beech, basswood, walnut, poplar, cherry, ash, elm, hickory, black gum, buckeye, and ironwood. In localities where the maple or walnut prevailed the type soon attained a wide reputation for its fertility and sustained crop-producing power. In general the lands occupied mainly by a beech forest were not so highly esteemed, while the growth of black gum and elm usually indicated low-lying areas within the type in which the natural drainage was too poor for their immediate occupation.

The gently undulating or rolling surface of the Miami clay loam was favorable for agriculture, and as the timber was removed a steadily increasing acreage was used for farm crops. At present over 80 per cent of the total area of the type is either arable land or is held in more or less permanent pastures, which are occasionally plowed for the production of a crop. The remainder of the type consists of woodlots, the somewhat hilly and stony areas which are occasionally encountered, and those steeper slopes along the margins of the type where the upland surface breaks down to the deeply trenched streams.

In general the Miami clay loam is highly prized as an agricultural soil. Its value varies, depending upon its location with respect to markets and to transportation facilities, from \$50 or \$60 an acre to \$250 or more where the land is located near the outskirts of the larger manufacturing cities.

There is little possibility that the area of the Miami clay loam under cultivation may be greatly extended. Such extension may occur only through the draining of areas which still remain somewhat swampy or through the clearing of forested areas which are required for the use of the farms upon which they occur. The former improvement might well be undertaken. The clearing of woodlots could scarcely be called an improvement.

The Miami clay loam is principally devoted to the production of corn, wheat, oats, and hay. Of the grain crops the acreage of corn takes first rank, the crop being extensively grown upon this type in Indiana, Michigan, Ohio, and Wisconsin. In general, the dent varieties of corn, either white or yellow, are produced in the more southern regions, while to a small extent in Michigan the flint corn is also grown upon this type. In Indiana the yields of corn range from 25 to 60 bushels per acre, with an average yield of something over 40 bushels per acre. In Michigan the yields range from 25 to 50 bushels, with an average of about 30 bushels per acre. In Ohio corn upon the Miami clay loam produces from 30 to 60 bushels per acre, with an average yield of about 40 bushels. In Wisconsin, the yield is 25 to 40 bushels per acre, the average being about 35 bushels. In the areas where the Miami clay loam has been mapped in Indiana the acreage annually devoted to corn exceeds that devoted to any other grain crop, wheat being second in acreage and oats third. In Ohio the acreage devoted to corn is usually greatest, although in some instances this is exceeded by either wheat or oats, while in Michigan wheat is the crop most extensively grown, with corn second in acreage and oats third. In general the Miami clay loam is not considered quite as good a corn soil as the Clyde silty clay loam, or the Marshall silt loam, when these occur in the same areas where the Miami clay loam is found. It is, however, an excellent corn soil measured by the average yields produced, even in the great corn-growing region of the central prairie States, and with proper drainage and careful preparation of the land annual yields averaging from 45 to 50 bushels may be expected. The corn is usually planted on sod which has been turned under, and not infrequently applications of stable manure are made. In general, the Miami clay loam occupies a region in west-central Ohio and east-central Indiana where the average production of corn is in excess of 40 bushels per acre. The only regions of any extent in which this yield is exceeded are those somewhat farther to the west, which are occupied mainly by the Marshall silt loam. Thus the Miami clay loam may be ranked as one of the important corn soils of the United States.

The majority of the farmers consider the Miami clay loam even better suited to the production of wheat than to the growing of corn. Of the total area of the Miami clay loam which has thus far been mapped, the counties in which the type constitutes more than one-half of the total area show an acreage devoted to wheat only less than that devoted to corn, and the computed average yield of wheat per acre in such counties in Indiana and Ohio is slightly more than 17 bushels. Wheat yields, ranging from 15 to 25 or 30 bushels per acre, have been reported in these States, and it is probable that the average for the Miami clay loam considerably exceeds the general average for the counties in which it occurs, since in each case it constitutes the best wheat soil of the area. A typical field of wheat on the Miami clay loam is shown in Plate XII, figure 2. Usually wheat is seeded on land upon which corn has been produced the preceding year. The winter varieties only are grown, spring wheat being practically unknown in this section. In Michigan the area devoted to wheat usually exceeds that devoted to any other grain crop on this soil type, and the average yields upon all soils in the counties of which soil surveys have been made are in the vicinity of 13 bushels per acre. The yields reported from this soil type in the same counties are 15 to 25 bushels per acre, indicating again that the Miami clay loam is a good wheat soil. Complete commercial fertilizers are sometimes used with the wheat seeding, but in general the fertilizers incorporated with the soil in the preparation of the land for corn are chiefly relied upon for the production of the succeeding wheat crop. In many cases wheat is produced two years in succession, and grass is seeded with the second crop. In other instances oats are seeded upon the corn land and followed by wheat.

The acreage devoted to oats in the counties in which soil surveys have been made and in which the Miami clay loam predominates is usually subordinate both to the wheat acreage and to the acreage in corn, although in some instances the acreage in oats is second only to that devoted to corn. For these counties Census statistics indicate an average yield of over 35 bushels of oats per acre. In Indiana the average yields for the Miami clay loam are stated in the soil survey reports at 30 to 35 bushels per acre, while in Michigan and Ohio the average yields are given as 40 to 60 bushels per acre. These estimates are fully verified by an examination of the statistics of yields in the counties mapped. As has been noted, oats frequently take the place of wheat as a first-year small-grain crop. In other instances, particularly in Michigan and the northern part of Ohio, the wheat is entirely displaced by oats, which are seeded only for a single year, being immediately followed by grass.

The area devoted to grass growing and hay production in the counties in which the Miami clay loam is the dominant soil type almost equals the area devoted to the production of the grain crops. This is due to the fact that grass usually occupies the ground for two or three years in the regular rotation, being cut for hay during the first and second years and not infrequently pastured the third year preparatory to breaking the ground for corn. The average yields for the counties in which soil surveys have been made exceeds 1.3 tons of hay per acre, and again the Miami clay loam may be credited with a yield greater than the average for these counties. On this type the yields range from 1 to 2 tons per acre, and the latter yield is sometimes exceeded. In all areas where the Miami

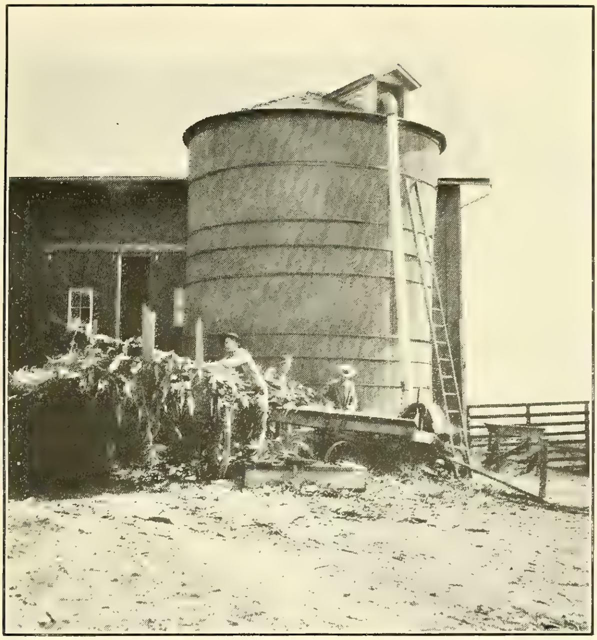

FIG. 1.—CUTTING CORN INTO THE SILO ON A DAIRY FARM LOCATED ON MIAMI SILT LOAM IN SOUTHEASTERN WISCONSIN.

FIG. 2.—TOBACCO ON MIAMI SILT LOAM, DEEP PHASE, IN SOUTHEASTERN WISCONSIN.

FIG. 1.—THRASHING SMALL GRAINS ON THE MIAMI SILT LOAM, DEEP PHASE, IN SOUTHEASTERN WISCONSIN.

FIG. 2.—A TYPICAL FIELD OF WINTER WHEAT ON THE MIAMI CLAY LOAM IN WEST-CENTRAL OHIO.

[Note the nearly level surface of this soil type.]

clay loam occurs the rougher and more sloping portions of the type, together with many areas which may be so covered with bowlders as to make cultivation difficult, are usually devoted to permanent pastures. The growth of native and tame grasses is excellent, and many pastures have been maintained from 50 to 100 years without reseeding or breaking the sod.

Of the principal crops suited to the middle temperate region, the Miami clay loam ranks high in the production of corn, wheat, oats, hay, and pasturage grasses. It is therefore one of the most important general farming soil types in the eastern part of the Central States.

In addition to the crops above mentioned, which dominate the agricultural practice of the region and the type, rye is also occasionally produced in Michigan, giving yields of 15 to 25 bushels per acre. Barley production is confined to southeastern Wisconsin, and the yields reported vary from 20 to 40 bushels per acre. Beans also constitute an important crop in southern Michigan, producing from 10 to 22 bushels per acre, and the latter yield is sometimes exceeded. In central Indiana tomatoes are being produced as a canning crop, yielding 200 bushels per acre, and in the same region green peas are raised for the city markets and as a canning crop, giving yields of about 2,000 to 2,500 pounds per acre. These constitute secondary special crops, chiefly of local importance and produced because of local market conditions.

In central and southern Michigan the Miami clay loam is also frequently used for the production of sugar beets. This crop takes the place of a part of the corn acreage in the regular rotation and has been produced extensively in this general region. The yields vary from 6 to 12 tons per acre, and the beets usually have a high sugar content and a high index of purity. The crop is grown only in the vicinity of established sugar-beet factories or in neighboring localities where transportation to the factories is well provided.

Another special crop producted on the Miami clay loam is the Spanish Zimmer tobacco, grown in the Miami region of southwestern Ohio. In this region the tobacco usually follows the corn crop, and the Miami clay loam is considered the best soil in the area for the production of tobacco. Nearly every farm includes a small field, ranging in size from 3 to 8 acres, while some growers produce from 10 to 30 acres each year. The tobacco grown upon this soil has good body, good sweating properties, and is fine fibered and elastic. The best filler leaf produced in the region is grown on the rolling upland areas of the Miami clay loam.

Among the tree fruits only apples and pears do well on the Miami clay loam, and even with apples it is necessary to discriminate in the selection of particular areas of the soil for the planting of orchards and also in the selection of varieties suited to such a heavy type of soil. It is only on the more rolling and better-drained uplands, where both surface and internal drainage are well established and where the air drainage over the orchard sites is good that apple orcharding upon a commercial scale should be undertaken. Lower lying areas where water drainage is interrupted or where the air does not circulate freely should be avoided for any extensive apple planting. The varieties best suited to this type are the old standard northern winter apples, the Rhode Island Greening and the Northern Spy. Of these varieties the soil is probably best adapted to the Greening. Although other varieties may be grown, these are preferable for commercial plantings.

The soil is altogether too heavy and the subsoil too dense for the production of peaches. Upon well-drained areas of the Miami clay loam the small fruits, particularly raspberries, currants, and strawberries, do well and may be grown successfully not only for home supply but also for near-by city markets.

There has been very little development of market gardening or trucking on this type, with the single exception of a locality in central Indiana, where tomatoes and green peas are the principal crops grown. There is an excellent opportunity for the production of cabbage and even of onions upon the lower lying portions of the type, especially where the dark-colored muck soil, which is frequently found in the hollows within the area of the type, has a depth of 6 to 8 inches or more.

In general, however, the Miami clay loam is too valuable as a grass and grain producing soil to be devoted to special crops, except in cases where local market demands are unusually strong, or where there are exceptional opportunities for rapid transportation to the larger cities.

As a result of the crop adaptations of the Miami clay loam, the proper disposal of the farm crops annually produced has led the majority of farmers into some form of animal production to supplement the sale of corn, or wheat, or other grain crops. In some parts of Ohio and in southern Michigan dairying constitutes the chief means of such crop disposal. Both corn and hay are extensively fed to dairy cows, while the areas of pasture are utilized for the summer production of milk. A part of the milk is shipped to the large cities, but the greater part of it is sold to local creameries and cheese factories. In this connection young stock, including calves and swine in large numbers, are fed for the purpose of a supplementary sale of beef, veal, and pork. In central Indiana and west-central Ohio the fattening of beef cattle is an important industry on this type. It is within the area ocupied by the Miami clay loam also that the principal sheep-breeding industry still maintained in the Eastern States is located. The sheep are now kept largely for the production of early spring lambs, although the wool clip constitutes an important source of revenue in many areas where this type has been encountered. Not as many sheep are kept within this general region as in the early days of wool production, but the number now maintained is steadily increasing with the increased price of spring lamb.

It is wholly impossible properly to till the Miami clay loam with light-weight farm teams or light tools. This is thoroughly recognized throughout practically all areas where the type occurs, and as a result the heavy two-horse teams and the more powerful forms of farm machinery are in common use. With these teams and implements deep plowing of the surface soil is possible, and thorough harrowing and tillage of the type can be conducted at later stages. The use of heavy teams and improved machinery is shown in Plate XIII, figure 1. A large part of the crops grown is planted or sown by the use of the two-horse corn planter or the large-size grain drill with fertilizer and seeder attachments. Disk harrows and riding cultivators are also used extensively. The farm equipment is usually adequate and substantial.

Because of the general practice of some form of stock raising within the territory occupied by the Miami clay loam, the farm buildings are large and substantial and the region is marked by well-painted houses, large and well-constructed hay and dairy barns, and in some sections by the necessary equipment of well-built tobacco barns. Not infrequently the farms on this type also possess the requisite equipment for the manufacture of maple sugar or sirup from the groves of sugar maples remaining in many areas. In general the teams, implements, and buildings upon the Miami clay loam give the appearance of a well stocked, adequately equipped, and well cared for farming territory. Typical farm buildings on the Miami clay loam in western Ohio are shown in Plate XIII, figure 2.

CROP USES AND ADAPTATIONS.

The soils of the Miami series are principally developed in the humid portion of the northern temperate region. Within the territory occupied by these soils the average annual precipitation ranges from slightly in excess of 40 inches in southern Ohio and Indiana to a little more than 30 inches in northern Michigan and Wisconsin. Over the greater part of the region it amounts to more than 32 inches, and in some localities exceeds 40 inches. Throughout the greater part of this area the precipitation is well distributed for crop production, since a large part of it occurs during the growing season.

The length of the growing season, or the normal interval between killing frosts in spring and fall, varies widely in the different sections of this territory. Thus in the southern areas, in southern and central Ohio and Indiana, the length of the growing season is approximately 175 days. The season becomes gradually shorter toward the north, comprising only about 150 days in central Michigan and Wisconsin. Only the most northern developments of the soils of this series have a growing season as short as 125 days under normal conditions.

Since the differences in altitude within this section are in general slight, there are no marked departures from the normal changes in climatic condition caused by differences in elevation. The protective influence of large bodies of water is felt in the case of those areas of the series which lie along the eastern shore of Lake Michigan to a distance of 30 miles or more inland, and, to a less extent, in areas along the western shore of the lake and around Green Bay.

These climatic conditions render possible the production of practically all of the staple crops suited to a temperate climate.

In considering the crop uses and adaptations of the different soils of the Miami series it must be held in mind that the different types are very unequally distributed through the region in which the series is developed. Fully 80 per cent of the total area of the Miami clay loam thus far encountered in the soil surveys lies in Ohio and Indiana. Approximately 50 per cent of the Miami silt loam has been encountered in these two States, while additional large areas occur in the southeastern part of Wisconsin where the climatic conditions are not materially different. All of the Miami fine sandy loam thus far mapped occurs in Michigan and Wisconsin, while the other more sandy and gravelly types, which are subordinate in total area, are chiefly confined to Wisconsin.

This uneven distribution of the types of the series will probably be accentuated as the soil survey work progresses, since it is known that large additional areas of the Miami clay loam and silt loam exist in western Ohio and central Indiana. There is thus a preponderance of the heavier soil types in the more southern latitudes and of the more sandy or loamy types farther north.

Moreover, the gravelly soils of the series and large areas of the more sandy soils are marked by a rather rough topography, and are less well suited to agriculture than the smoother, heavier members of the series.

All of these circumstances tend toward the partial development only of the sandy and gravelly soils and toward a restricted crop use, while the fine sandy loam and heavier members of the series are extensively occupied for the production of a wide range of staple crops.

The Miami sand is of very limited extent, and is too droughty to give even fair yields of staple crops. Low yields of corn, oats, rye, and clover are secured. If this soil were favorably located with respect to markets it would constitute an early truck and fruit soil of considerable value.

The Miami gravelly sandy loam and gravelly loam are somewhat better suited to crop production, giving fair yields of corn, oats, rye, barley, and hay under favorable conditions of rainfall. They are both subject to drought and are chiefly farmed in connection with other soil types. A large total area of each type is used for permanent pasture.

The Miami fine sand produces low yields of the general farm crops. Corn yields about 25 bushels, oats 22 bushels, rye 12 bushels, and timothy and clover hay about 1 ton per acre. It is a fairly good potato soil and beans are successfully grown. About three-fourths of the total area of the type thus far encountered in the soil surveys is under cultivation, while the greater part of the remainder is used for pasture.

The Miami sandy loam has been encountered only to a very limited extent. Its crop uses are about the same as those of the Miami fine sand, but the yields of the staple crops are slightly greater.

The Miami fine sandy loam is the coarsest textured soil of the series that is well suited to the extensive production of the staple farm crops. Practically all of the area of this type so far mapped occurs in the cooler portion of the general region occupied by the soils of the series. The type is everywhere well drained, and the compact subsoil serves to retain moisture to a sufficient degree for maturing crops under conditions of normal rainfall. As a result practically all the type has been cleared and is used for general and special forms of agriculture. A study of the crop uses of this type shows that corn, oats, and hay occupy the largest acreages upon it, producing fair to good yields. Barley, wheat, and rye are grown to a small extent. The yields of wheat are low, and the acreage devoted to this crop is decreasing. Beans are grown to a considerable extent in Michigan, producing fair average yields. Potatoes are well suited to this soil, and are grown to some extent as a cash crop in both Michigan and Wisconsin. The type occurs extensively within the Michigan fruit belt, which extends inland for a distance of 30 miles or more from the eastern shore of Lake Michigan. In this region it is used for apple and peach orcharding and for the growing of cherries, grapes, and small fruits. It is found to be well suited to these crops. Dairying constitutes the principal form of animal industry on the Miami fine sandy loam, although some beef cattle are fattened and hogs also are grown in connection with dairying. Sheep are raised in some localities.

The Miami loam is chiefly developed in southern Michigan, with large areas in about the same latitude in Wisconsin. The occurrence of this type in the more northern sections affects its crop uses, and it is probable that the largest acreage is annually devoted to hay production. Corn is second in acreage and oats are third. The area devoted to the production of winter wheat is next to that used for oats. The yields of all of these crops are good. Corn probably averages something more than 40 bushels per acre. Hay produces about 1½ tons. Oats yield an average of about 40 bushels per acre. The average wheat yield is about 15 bushels. Rye and barley also are grown, giving good average yields. Beans constitute the most important special crop, being extensively grown upon the Miami loam in southern Michigan. The average yield per acre is about 15 bushels. Potatoes are grown chiefly for home use, but a surplus is annually marketed, and the type might well become an important potato-producing soil. Orchard fruits are grown in favored localities, chiefly for home use. Both in Michigan and Wisconsin the dairy industry is well developed on the Miami loam. The crops grown are well suited to dairy feeding, nearly all of the farms include some land best suited to permanent pasturage, and the climatic conditions are suitable for the manufacture of butter and cheese. In connection with the dairy industry, some hogs are fattened. In the bean-growing region sheep also are raised. But few beef cattle are kept on this type.

The Miami silt loam has been mapped chiefly in Indiana and Ohio. Large areas are also found in the southern part of Wisconsin under similar climatic conditions. The larger areas of the type lie well within the "corn belt" and this crop occupies the largest acreage on the Miami silt loam. All of the better drained portions of the type are well suited to corn production, and the average yield obtained is in the neighborhood of 40 bushels per acre. It is an important corn-producing soil although the average yields secured from it are frequently exceeded by those produced on the darker colored soils associated with it. There is a general tendency over the entire type to produce as large an acreage of corn as is possible each year. The acreages given to oats and to hay are almost equal over a considerable part of the Miami silt loam. In the more southern regions of its occurrence the climatic conditions are not especially favorable for oat production, but near its northern limits, as in Wisconsin, this crop thrives and the largest acreage sown to grain is annually devoted to oats. The average yield produced under all conditions of climate and soil is about 40 bushels per acre. The yields in southern latitudes are generally less than those secured farther north. The hay grown on the Miami silt loam is chiefly mixed timothy and red clover, although some localities produce clover alone. The average yields range from about 1¼ tons per acre in more southern localities to 1¾ tons in southern Wisconsin. The deep phase of the type is one of the best hay soils in the Central States. Winter wheat is extensively grown on the Miami silt loam in Ohio and Indiana, and constitutes the chief small-grain crop in the more southern locations. The yields range from 12 to 30 bushels per acre and statistics of production indicate that wheat on this soil will average from 16 to 17 bushels per acre over large areas through considerable periods of time. It is evident that the acreage of wheat grown upon this type is being reduced somewhat, and it is claimed that the yields have decreased. It is probable that the greater profits secured from the production of corn have contributed to the restriction of wheat production. Barley is grown to some extent on this soil in southern Wisconsin, giving an average yield of 20 bushels or more per acre. Several special crops have been grown with success in different areas of the Miami silt loam. In central Indiana tomatoes are produced for canning, giving a fair tonnage of late tomatoes. Beans are grown to a limited extent in southern Wisconsin. In this region some tobacco also is grown. Nearly all farms upon the type produce sufficient potatoes for home use, but the growing of this crop on a commercial scale is not practiced. Sugar beets are grown in southern Wisconsin, giving large yields of beets of fair quality. The better drained areas of the Miami silt loam in southern Wisconsin have been found to be well suited to growing alfalfa. This crop produces from 2½ to 5 tons per acre.

In all of the more southern localities of its occurrence the Miami silt loam is chiefly used for the production of grain and hay. In part these crops are fed to beef cattle and to hogs, while a part of the grain is sold. In the more northern regions a profitable dairy business is developed on the basis of the large acreage of hay and pasture maintained on the type, supplemented by the use of corn as silage. The crops sold are chiefly the small grains. In general, the type of farming and the character of the crops grown vary to a considerable degree with climatic conditions.

Approximately 75 per cent of the total area of the Miami clay loam which has thus far been mapped occurs in western Ohio and central Indiana. It is certain that from 50 to 80 per cent of the total area of many of the counties in this section is occupied by this soil and the closely related Miami silt loam. The dominance of the type is so marked that the general agricultural practices of the section may be correlated with this soil with a reasonable degree of accuracy. A study of the statistics of crop production in this region shows that the area annually devoted to corn growing is double that given to any other single crop. It is only slightly less than the combined acreage of hay, oats, and wheat, the three next most important crops. This section has a growing season of 160 to 180 days, and is also provided with an abundant rainfall, except at rare intervals. Corn is generally recognized as the most profitable staple crop, and the constant tendency is to increase the acreage planted.

The availability of the Miami clay loam as a corn soil under these climatic conditions is well shown by the average yields secured over large areas and through periods of many years. The various soil survey reports indicate that the range in yield is from 25 to 60 bushels per acre, with a general average of 40 bushels or more. Statistical data confirm these figures, showing an average yield of corn of approximately 44 bushels per acre for the western Ohio counties where this soil is dominant and of 45.4 bushels per acre for similar counties in central Indiana. In each case these yields are above the average for the States. While the figures may be a little high, due to the inclusion of average yields from excellent corn soils found along numerous river terraces and from appreciable areas of black upland soils, they are fairly representative of the capabilities of the Miami clay loam for corn growing. These average yields are only less than those secured from the dark prairie soils of the corn belt, occurring immediately to the west of the region where the Miami soils dominate. All evidences of high present yield, increasing acreage, and numerous instances of yields considerably in excess of the average production indicate that the Miami clay loam is one of the most important corn soils of the eastern part of the central corn-growing belt. The soil survey reports consistently indicate that portions of the type which either possess good natural drainage or which have been tile drained produce corn crops above the average. They also show that yields are increased by the practice of a regular rotation which includes the production of clover or mixed clover and timothy, and that the use of organic manures is essential to the production of high yields of corn.

The acreage in hay crops is second to that devoted to corn in those Ohio and Indiana counties in which the Miami clay loam predominates. The average yields of mixed timothy and clover hay are 1.4 tons per acre in the Ohio counties and a little over 1.3 tons per acre in the Indiana counties. In both cases these yields are above the averages for the respective States. The greater part of the hay produced consists of mixed timothy and clover, although a large amount of clover alone is grown in both these States.

Oats are third in total acreage in these counties, covering but slightly less area than hay. The yields per acre are slightly under 30 bushels in each State, being less than the State averages. The yields of this crop on the Miami clay loam as it occurs in Michigan and Wisconsin are higher than in the more southern localities.

FIG. 1.—FOUR-HORSE TEAM AND RIDING PLOW USED IN THE TILLAGE OF THE MIAMI SILT LOAM AND CLAY LOAM.

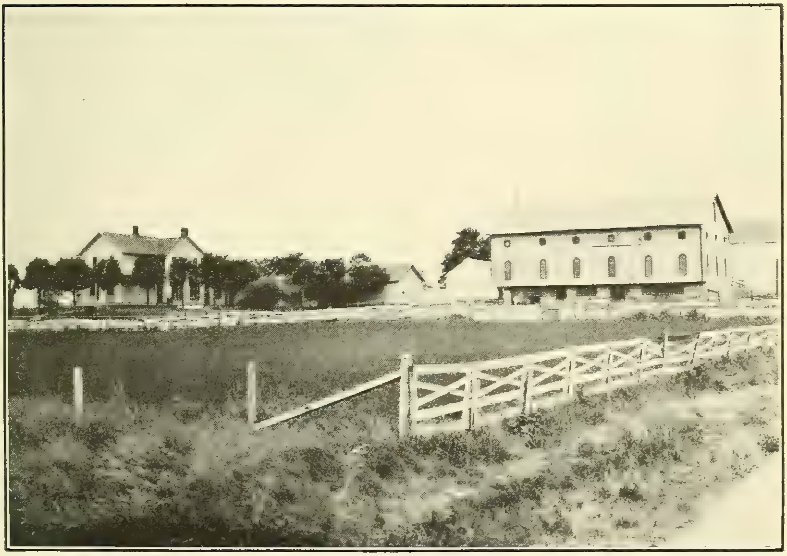

FIG. 2.—TYPICAL FARM BUILDINGS ON THE MIAMI CLAY LOAM IN WESTERN OHIO.

The Miami clay loam has its greatest development in the eastern region where winter wheat still constitutes an important crop. The acreage reported in wheat for the Ohio counties dominated by this type is decidedly less than that devoted to oats, but in Indiana the acreage nearly equals that in oats. In both cases winter wheat ranks fourth in acreage among the staple crops. In both States it is generally reported that the acreage in winter wheat is being reduced, although this crop retains an important place in the farming system. The average yield for the Miami clay loam in western Ohio is approximately 14 bushels per acre, the yields ranging from 12 to 20 bushels. In Indiana the average yield is 15 to 16 bushels per acre, with about the same range. In both cases the yields are slightly less than the averages for the respective States. Considerable wheat is also grown upon the Miami clay loam in southern Michigan, and the yields reported are larger than in either Ohio or Indiana. They average slightly less than 20 bushels per acre. The type is undoubtedly well suited to wheat, but the higher returns per acre secured from corn production have tended to increase the acreage of that crop somewhat at the expense of wheat. In the dairying regions, also, the desire to produce the largest possible acreage of forage crops on each farm has led to a gradual abandonment of wheat.

Barley, rye, and buckwheat are grown only to a small extent on the Miami clay loam, although they give good average yields in the more northern localities.

Tobacco constitutes a special crop on the Miami clay loam in southwestern Ohio and adjoining counties in Indiana. On many farms from 5 to 20 acres are annually devoted to tobacco and the yields are good, averaging 1,200 pounds or more per acre. Tomatoes also are grown to a limited extent in central Indiana, chiefly for canning purposes. The type is well suited to this crop.

The Miami clay loam is developed to some extent in the southern counties of Michigan, and small areas are found in southeastern Wisconsin. In Michigan it is probable that the hay crop occupies the largest acreage of any single crop on the type. Mixed timothy and clover constitute the principal hay crop, giving an average yield of about $1\frac{1}{4}$ tons per acre. Corn is second in acreage, and produces an average yield of about 35 bushels per acre in this more northern latitude. Oats constitute the principal small-grain crop, and the average yield for the Miami clay loam in both Michigan and Wisconsin is undoubtedly in excess of 35 bushels per acre. Some beans and sugar beets are produced on the type.

The dominant form of agriculture upon the Miami clay loam is grain and grass farming. This is supplemented to a small extent and in restricted localities by the production of special crops such as tobacco and tomatoes. A considerable part of the corn grown is sold, while all of the wheat is produced for cash sale. The balance of the corn, the greater part of the oat crop, and nearly all the forage are fed upon the farm. In Ohio and Indiana the feeding operations consist chiefly of the fattening of cattle bought for this purpose. Associated with the feeding of stock is the fattening of hogs raised on the farm. Many of the counties in western Ohio and central Indiana which are dominated by the Miami clay loam and the Miami silt loam, annually sell more than a million dollars worth of these two animal products. In fact, the chief form of animal industry consists of fattening beef cattle, the cattle being followed in the feed lot by hogs. Dairying is only developed in these counties to a limited extent where local markets or shipping facilities render it particularly profitable. In Michigan, however, the dairy industry rather exceeds in importance the fattening of beef cattle. Hogs are grown both on the dairy farms and with the beef cattle. In Wisconsin the type is found in the dairy section, and the growing of forage crops and the feeding of dairy cows are the chief industries.

SUMMARY.

A general consideration of the crop uses and adaptations of the soils of the Miami series indicates that the more gravelly and sandy soils of the series are relatively unimportant agriculturally because of limited total extent, defective moisture-holding capacity, and a generally rougher topography. Yet some of these soils, particularly the Miami fine sand and sandy loam, would constitute valuable special-crop soils if they were suitably located with respect to markets.

The Miami fine sandy loam, loam, silt loam, and clay loam comprise by far the greatest area of the soils of this series, and they are well suited with respect to topography, drainage and moisture conditions, and climatic surroundings to the growing of the most important staple crops of the temperate region. The Miami fine sandy loam is the coarsest textured soil of the series which is well suited to general farming. It is a fairly good soil for the production of corn, oats, and hay, and is well suited to the growing of beans and Irish potatoes. The occurrence of considerable areas of the type under special climatic conditions has encouraged its use for orcharding and the growing of grapes and small fruits.

The Miami loam is an excellent general-purpose soil, and is extensively used for the growing of corn, oats, and hay, with beans as the chief special crop. It is also suited to orcharding upon a domestic scale. Climatic conditions have favored the development of the dairy industry.

The Miami silt loam and clay loam are closely associated in geographic distribution, and are quite similar in their present crop uses. Owing partly to the climate both types are used chiefly for corn growing, with hay and oats occupying large acreages. Winter wheat is extensively grown upon both soils, giving moderate yields. The corn acreage is increasing while that in wheat is decreasing on both soil types. In general, the fattening of cattle and the raising of hogs constitute the chief forms of animal industry on both types, although the dairy industry is well developed in the more northern regions of their occurrence. Special crops, with the exception of tobacco and tomatoes, are not extensively grown.

The principal types of the series rank high as general farming soils, giving yields of the staple crops which equal or exceed the average of the States where they are most extensively developed. It is generally true that the heavier members of the series are much improved by tile underdrainage, while all of the types require the addition of organic matter in the surface soils either by the use of stable manure or the plowing under of green manure. It has been found that while the subsoils of the different types are generally calcareous, the application of lime to the surface soils is beneficial in conjunction with the growing of clover and other leguminous crops.

Practically all the available areas of the principal types have been cleared and are utilized for agricultural purposes, only the rougher land remaining in woodlots or in permanent pastures. While crop yields are, in general, satisfactory, it has been found that careful attention to crop rotation, the incorporation of organic manures, the use of commercial fertilizers with the small grain crops, liming, and tile underdrainage on the heavier types aid in increasing crop yields.

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PROFESSIONAL PAPER.

THE PRODUCTION AND FERTILIZER VALUE OF CITRIC-SOLUBLE PHOSPHORIC ACID AND POTASH.

By Wm. H. Waggaman,
Scientist in Investigation of Fertilizer Resources.

INTRODUCTION.

The extraction of potash from silicate rocks or the rendering of this alkali soluble in water has been and probably will continue to be for a long time the object of numerous investigations.

Ross[1] has investigated many of these processes and discussed several in some detail. For convenience he divides them into three classes, as follows: (1) Processes which yield potash as the only product of value; (2) processes which yield potash and some other salable material as a by-product; (3) processes in which two or more operations are combined in one, yielding a fertilizer containing two or more of the constituents, potash, phosphoric acid, and nitrogen. He describes two methods for obtaining potash from feldspar by treating mixtures of that mineral and lime, collecting the potash thus liberated, and using the residue for the manufacture of cement. The potash obtained by these processes, however, is in the form of oxide or hydroxide, and is therefore more valuable for other purposes than for the manufacture of fertilizers. Ross also tried heating together feldspar and lime with the addition of phosphate rock, but found that the latter substance did not enter into the reaction, there being no increase in the quantity of potash thus obtained over that produced by the ignition of feldspar and lime alone.

The production in a single operation of available phosphoric acid and potash from insoluble minerals, however, presents possibilities which are particularly attractive, and several processes have been devised to accomplish this end. It is the purpose of this paper first to discuss these existing methods and then to describe a process

[1] Jour. of Ind. and Eng. Chem., 5, No. 9, pp. 725–729 (1913).

recently devised in this laboratory for rendering the phosphoric acid and potash in a mixture of phosphatic limestone and feldspar " citric soluble."

EARLIER METHODS.

There are four[1] recorded processes for making a phosphoric acid-potash fertilizer from phosphate rock and feldspar. In chronological order they are as follows:

A method devised by Charles Bickell[2] in 1856, which consists in heating in a reverberatory furnace to a light redness for two hours an intimate mixture of 1 part feldspar, 0.5 part phosphate of lime, and 3 or 4 parts of air-slaked lime. Bickell claims that both phosphoric acid and potash in available forms are obtained by this treatment.

This experiment was repeated in this laboratory, using feldspar, Tennessee phosphatic limestone, and calcium carbonate in the following proportions:

	Per cent.
Feldspar (13.7 per cent K_2O)	22.2
Phosphatic limestone (23 per cent P_2O_5)	11.1
Calcium carbonate	66.7

Assuming that the carbon dioxide present in the calcium carbonate and phosphatic limestone was the only substance volatilized during the process, the product should have contained after ignition 4.38 per cent potash (K_2O) and 3.4 per cent phosphoric acid (P_2O_5). Analysis of the residue, however, gave the following results:

	Per cent.
K_2O:	
Total	1.94
Water soluble	.18
P_2O_5:	
Total	3.62
Citric soluble	1.40

These results show that over 44 per cent of the potash present in the mixture was volatilized upon ignition, and of that which remained in the residue only 9 per cent was water soluble. While none of the phosphoric acid was volatilized, less than 39 per cent of the total amount present was soluble in a 2 per cent solution of citric acid (the method usually employed for determining the availability of phosphoric acid in basic slag).

The second process for the manufacture of a phosphate-potash fertilizer from feldspar and phosphate rock was devised by Frederick Klett[3] in 1865. It consists of heating to redness for five hours an intimate mixture of one part feldspar, two parts carbonate of lime, one part phosphate rock, and adding for each part of K_2O in the feldspar two parts of calcium fluoride. It is claimed that a solu-

[1] Since transmitting this manuscript several other processes have been devised. The author regrets that it is impracticable to consider these methods in the present paper.

[2] U. S. Patent No. 16111 (1856).

[3] U. S. Patent No. 49891 (1865).

ble silicate of lime and potassium phosphate are thus obtained. In view of the fact that the percentage of potash in the mixture is relatively small and that the time of heating is very long, it is hardly likely that the value of the product would cover the cost of manufacture. Moreover, the claim that phosphate of potash is formed in the operation is apparently not justifiable. It was thought advisable, however, to test this process also. A mixture of the following composition was made up and ignited in a muffle furnace for five hours at red heat:

	Per cent.
Feldspar (13 per cent K_2O)	24.21
Phosphate rock (32.8 per cent P_2O_5)	24.21
Calcium carbonate	48.42
Calcium fluoride	3.15

The slightly sintered product of this mixture was finely ground and analyzed both for potash and phosphoric acid. If carbon dioxide were the only volatile substance formed by heating the above mixture the final product should have contained 4 per cent of K_2O and 10.09 per cent of P_2O_5. Actual analysis of the material, however, gave the following results:

	Per cent.
K_2O:	
Total	0.60
P_2O_5:	
Total	10.51
Citric soluble	4.15

Here again, as in Bickell's process, the potash nearly all volatilized, while less than one-half of the phosphoric acid present in the residue is citric soluble.

The third process for rendering the phosphoric acid and potash of rocks available for fertilizer purposes is that of Coates,[1] which consists in adding to the sterlized rock mixture certain microorganisms that effect the breaking down of the rock minerals. It is understood that the material thus prepared is being tried out experimentally by actual field tests, the results not yet having been reported.

In 1912 Haff[2] devised a process for making potassium phosphate from a mixture of feldspar and phosphate rock. The method is based on the fact that at high temperatures and in the presence of silica and a nonvolatile base, both potash and phosphoric acid are volatilized. Haff claims that 95 per cent of the potash and phosphoric acid of natural rocks can be driven off at a temperature of 2,000° C. and collected by passing the fumes through scrubbing towers. While this method has not been tried out in this laboratory, the cost of maintaining the high temperature necessary for the decomposition

[1] U. S. Patent No. 947795 (1910). [2] U. S. Patent No. 1018186 (1912).

of the minerals and the expense of collecting and recovering the potash and phosphoric acid thus violatilized make it very doubtful if this process is commercially practicable.

THE FUSION OF FELDSPAR AND PHOSPHATE ROCK.

The solubility of phosphates in certain organic solutions has for a long time been regarded as a test of their agricultural availability. The nature and strength of the organic solvent used differs in various countries, and since each process is based on an arbitrary standard, it can only give corresponding results when conditions are the same. But in spite of the fact that none of these methods is founded upon a strictly scientific basis, it is generally thought that phosphates soluble in such solutions are under soil conditions more active than those which do not dissolve in the same mediums.

The beneficial effect of the phosphoric acid in finely ground steamed bone is unquestioned, and although little of it is water soluble, a neutral solution of ammonium citrate will dissolve from 12 to 31 per cent of the acid, depending on the temperature of the solution and the time of contact.[1] It is also an indisputable fact that excellent results have been obtained by the use of basic slag as a fertilizer, and it is claimed that these results are commensurable with the amount of citric soluble phosphoric acid present in the material.

It has therefore become customary to regard citrate or citric soluble phosphoric acid as having a commercial value nearly equal to that of water soluble phosphate.[2] While this is true of phosphates, the same view is not taken of potash-bearing substances, since practically all of the potash carriers used in agriculture are water soluble. The potash in the ordinary soil minerals is almost entirely insoluble in water, and but slightly soluble in the mineral acids, but if the potash present could be converted into a citric soluble form there seems to be no reason why it should not be considered as available to crops as citric soluble phosphoric acid.

During some investigations carried on in this laboratory on the possibilities of rendering the slags from the iron and steel industries available for fertilizer purposes,[3] attempts were made to fuse together mixtures of feldspar and phosphatic limestone with a view to obtaining both the potash and phosphoric acid present in an "available" form. Mixtures containing various proportions of these two

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[1] Huston, H. A., 32d Annual Report Indiana State Board of Agriculture, p. 230 (1883); Wiley, H. W., Principles and Practice of Agricultural Analysis, vol. 2, p. 47; Wheeler, H. J., Manures and Fertilizers, p. 172 (1913).

[2] A report of a conference of the experiment stations of New York, New Jersey, and New England, Mar. 1, 1911, indicates that citrate soluble phosphoric acid has about nine-tenths of the fertilizer value of water soluble phosphoric acid.

[3] Bul. 95, Bureau of Soils, U. S. Dept. of Agr., 1912.

substances were ignited at temperatures ranging from 1,200° to 1,400° C., but only viscous fusions were obtained and the potash and phosphoric acid in none of these were soluble in 2 per cent citric acid, the solution conventionally employed to determine the availability of phosphoric acid in basic slag.

The failure to obtain liquid fusions was at the time attributed to the absence of iron or manganese, or both, in the mixtures, since it is well known that these elements impart fluidity to slags in the manufacture of iron and steel. Subsequent experiments have proved that such was the case, for on the addition of small quantities of these two elements to certain mixtures of feldspar and phosphatic limestone liquid fusions were obtained, and these were found to contain both phosphoric acid and potash in a citric soluble form.

In Table I is given the composition of the materials used in the experiments.

TABLE I.—*Composition of feldspar and phosphatic limestone used.*

Material.	SiO_2.	Al_2O_3.	CaO.	K_2O.	Na_2O.	P_2O_5.	CO_2.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Feldspar	65.7	18.4	....	13.7	2.2	....	....
Phosphatic limestone	32.4	....	37.1	....	....	20.0	10.5

The above materials were mixed in various proportions and small amounts of hematite and manganese dioxide were added. Each mixture was then placed in a graphite crucible and heated in a muffle furnace until fusion took place. The melts were then cooled, finely ground, and analyzed for phosphoric acid and potash (both total and citric soluble).

It was found that while citric soluble potash can be readily obtained by heating various mixtures of feldspar and phosphatic limestone over a wide range of temperatures, the limits within which the maximum yields of citric soluble phosphoric acid are obtained are quite narrow, both in respect to the proportion of the ingredients in the mixture and the length of time of heating.

The percentages of the ingredients used in the various mixtures before ignition and the composition of the melts are given in Table II.

TABLE II.—*Proportions in which ingredients were mixed and analyses of melts obtained.*

Sample No.	Amount of material used.				Properties of fusion.	Analysis of melts.			
	Feldspar.	Phosphatic limestone.	Fe_2O_3.	MuO_2.		P_2O_5 soluble in citric acid.	Total P_2O_5.	K_2O soluble in citric acid.	Total K_2O.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
25 S	42.8	42.8	8.6	5.7	Slightly viscous	2.12	9.76	6.56	6.82
28 S	37.5	50.0	7.5	5.0	do	1.50	11.40	5.32	5.68
33 S	46.8	37.5	9.4	6.3	Liquid	7.22	7.21	6.50	6.48
34 S	37.5	42.5	12.5	7.5	do	5.80	[1] 9.13	4.50	5.26

[1] Not determined by analysis, but calculated from the quantity of feldspar added.

Table II shows that nearly all of the potash present after fusing the various mixtures was soluble in 2 per cent citric acid, but in only one case (33S) was the total phosphoric acid present after ignition soluble in this same medium.

Further investigation showed that both the quantity and solubility of the phosphoric acid remaining in this melt was greatly influenced by the temperature and length of time of heating. In order to test the effect of these two factors on the composition and nature of the melt, this mixture (33S) was heated for various periods of time and at several different temperatures. The melts thus obtained were cooled, ground, and analyzed. The results of these analyses are given in Table III.

TABLE III.—*Properties and analyses of melts obtained by heating together phosphatic limestone and feldspar with small amounts of hematite and manganese dioxide.*

Sample No.	Temperature of melt.	Time of heating.	Properties of fusion.	P_2O_5.		K_2O.	
				Citric soluble.	Total.	Citric soluble.	Total.
	° *C.*	*H. m.*		*Per cent.*	*P. ct.*	*Per cent.*	*Per cent.*
33 SA	1,200	0 20	Viscous	1.82	8.50	5.98	6.76
33 SB	1,400	0 40	Liquid	7.22	7.21	6.50	6.48
33 SC	1,400	1 40	Less liquid	2.50	3.76	Lost.	5.48
33 SD	1,400	4 40	Viscous	1.20	2.88	Not determined.	Not determined.

It is shown in Table III that when the mixture was heated to 1,200° C. for about 20 minutes the fusion was not complete, and only a little more than 21 per cent of the total phosphoric acid present was citric soluble; over 88 per cent of the potash, however, was soluble in the same medium. Upon raising the temperature to 1,400° C. and maintaining it there for 20 minutes the fusion became quite fluid, and, although small amounts of potash and phosphoric acid were lost through volatilization, the remainder of these ingredients was entirely soluble in 2 per cent citric acid. After heating the mixture for one hour longer at the same temperature almost 50 per cent of the phosphoric acid and more than 15 per cent of the potash were volatilized, and upon heating for three hours more the phosphoric acid was still further reduced.

The sample richest in citric soluble phosphoric acid and potash (33S B) was submitted to a microscopic examination by Mr. W. H. Fry of this bureau. It was found to be isotropic and possessed all the external characteristics of a glass.

This was to be expected, however, since the melt was cooled too rapidly to allow of its crystallization.

SOLUBILITY OF THE POTASH OF THE SLAG IN WATER SATURATED WITH CARBON DIOXIDE.

The fact that the phosphoric acid of basic slag is fairly soluble in water saturated with carbon dioxide is taken as an added proof of its availability under soil conditions. It was thought advisable, therefore, to test the solubility of the potash in the slag product (33SB) in this same medium, comparing this solubility with that of the potash in feldspar.

Considerable work has been done on the so-called solubility of orthoclase in water and in various other solvents.[1] It is recognized, however, that this mineral has no definite solubility in water, but the dissolved material undergoes practically complete hydrolysis or decomposition, the amount of this decomposition being considerably affected by the fineness of the mineral, the method of grinding it (whether wet or dry), the quantity and temperature of the water used, and the length of time the water is allowed to act.

In Table IV the apparent solubility of feldspar in pure water and in water saturated with carbon dioxide as determined by several investigators is given. Few of these results are comparable, owing to the different conditions under which the experiments were conducted, but they are of interest in showing what widely divergent results are obtained by varying these conditions.

[1] Roger Brothers, Am. Jour. Sci. and Arts. 2, 401 (1848); Daubrer, A., Études Synthétiques de Géologie Expérimentales, pp. 268–275 (1879); Clarke, F. W., Jour. Am. Chem. Soc., 20, 739 (1898); Lemberg Inaugural Dissertation Dorkat (1877); Cameron and Bell, Bul. 30, Bureau of Soils, U. S. Dept. of Agriculture (1905); Cushman and Hubbard, Bul. 28, Office of Public Roads, U. S. Dept. of Agriculture (1907). See also Cameron, Proceedings Eighth International Congress of Applied Chemistry, New York, 1912, Vol. XV, p. 43 et seq.

TABLE IV.—*Solubility of feldspar in water and in water saturated with CO_2, as determined by various investigators.*

Investigator.	Amount of feldspar used.	Amount of water used.	Time of contact.	Method of treatment.	Amount of K_2O dissolved from feldspar.	Amount of K_2O in solutions.
	Grams.	*Grams.*			*Per cent.*	*P. p. m.*
Daubrer	3,000	5,000	192 hours	Triturated in revolving cylinder.	0.420	2,520.0
Do	2,000	(CO_2) 3,000	240 hours	do	.013	90.0
Cameron and Bell	2	1,000	14 months	Allowed to stand in contact with water.	.085	1.7
Do	2	(CO_2) 1,000	do	do	.125	2.5
Cushman and Hubbard.	25	100	Not given	Mineral ground while dry.	[1] .100	[1] 250.0
Do	25	100	do	Mineral ground wet.	[1] 1.280	[1] 3,200.0

[1] Total residue.

In the experiments for comparing the solubility of the potash in 33SB with that of feldspar, a large quantity of the slag product was first prepared and ground to pass a 200-mesh screen. On analysis this material showed the following composition:

	Per cent.
K_2O citric soluble	5.14
K_2O total	5.43
P_2O_5 citric soluble	6.32
P_2O_5 total	6.31

Two samples of this slag of 25 grams and 0.25 gram, respectively, and the same quantities in weight of feldspar (ground equally fine) were placed in platinum-lined brass cylinders, 100 cubic centimeters of water were added to each and carbon dioxide under an average pressure of $1\frac{1}{3}$ atmospheres was passed through the solutions for one week. At the end of that time the amount of potash dissolved from each sample was determined by analysis of the solutions. The results of these analyses are given in Table V.

TABLE V.—*Solubility of the potash in the slag product (33SB) in water saturated with carbon dioxide, compared with that of the potash in feldspar.*

Material used.	Amount of material used.	Amount of water employed.	Potash dissolved.	
			Potash in solution.	Percentage of total potash in sample.
	Grams.	*C. c.*	*P. p. m.*	
Feldspar	25.00	100	127.5	0.36
Do	.25	100	4.7	1.37
Slag (33SB)	25.00	100	150.0	1.11
Do	.25	100	11.9	8.76

In the case where large samples (25 grams) of slag and feldspar were used the resulting solutions differed but little in respect to their potash content, but considering the fact that the sample of slag contained less than one-half as much potash as the feldspar, the percentage of potash dissolved from the former was nearly four times as great. Moreover, while no quantitative determinations were made of the total solids in solution, the amount dissolved from the slag was apparently many times greater than that dissolved from the feldspar.

In the case where only 0.25 gram samples of the two substances were used the slag yielded a solution nearly three times as strong (in respect to potash) as the feldspar, and when the quantity of potash in the two substances is considered the percentage dissolved from the slag was nearly seven times greater.

RESULTS OF POT TESTS WITH SLAG FERTILIZER.

Although the solubility of the potash and phosphoric acid in the slag product was indicative of its agricultural value it was thought advisable to test its merits by actually growing plants in soils treated with this material, and comparing their growth with that of plants grown under similar conditions in the same soils untreated and treated with well-known potassic and phosphatic fertilizers.

The experiments were conducted by Mr. J. J. Skinner of this bureau. The wire-basket method described in Circular 18, Bureau of Soils, was employed, using wheat seedlings.

Three types of soil were used, namely, the Carrington silt loam from Wisconsin, the Hagerstown loam from Pennsylvania, and the Volusia silt loam from New York. These soils are described in Bulletin 96 of this bureau as follows:

> The Carrington silt loam consists of a dark-brown to black silt loam, having an average depth of about 12 inches. The subsoil is a yellowish-brown to pale-yellow silty clay loam or silty clay. The topography is mainly level to undulating. The soil represents a residual stratum derived from glacial till. The type is admirably adapted to the general farm crops, including wheat, corn, oats, barley, rye, flax, and grass.
>
> The Hagerstown loam is a brown or yellow loam averaging about 12 inches in depth. The subsoil is a yellow or reddish clay loam to a depth of 24 inches, but frequently grades into a stiff, yellowish-red clay. The type occupies rolling valley land, and is derived from the weathering of pure limestone. This is typical corn soil. It is one of the best general farming types in the eastern States, and is used for corn, tobacco, wheat, grass, and apples.
>
> The soil of the Volusia silt loam, to an average depth of 8 inches, is a gray to brown silt loam. The subsoil to a depth of 2 feet is a light-yellow silt loam, at which point mottlings of gray or drab are encountered. Both soil and subsoil

contain a high percentage of flat fragments of shale and sandstone, ranging from 1 or 2 inches to a foot or more wide. In addition, a considerable quantity of finely divided shale fragments is found in both soil and subsoil. The subsoil usually rests at varying depths below 18 inches on beds of shale or sandstone rock. The type is derived from the weathered products of the shale and sandstone, reworked by glaciation and slightly modified by extraneous glacial material. It occupies rolling and hilly land and is frequently interrupted or bordered by steep slopes not suited to agricultural purposes. The Volusia silt loam where properly cultivated is a good soil for timothy and small grains. In the eastern part of the region where it occurs it lies at too high an elevation to be well adapted to corn. In this region buckwheat and potatoes are grown to advantage.

Each of the above soils was treated with applications of the slag fertilizer, and wheat seedlings were planted. The plants were grown for a period of three weeks and then weighed and compared with those grown under similar conditions in untreated soil and in soil treated with other forms of potash and phosphatic fertilizers. Since the Volusia silt loam responds readily to treatment with lime, two sets of experiments were run with this soil. In the first no lime was used except that furnished by this slag fertilizer, but in the second set of tests the soil was limed at the rate of 2 tons to the acre. This was done in order to make sure that any beneficial effect observed from the slag treatment was not entirely due to the basic character of this material.

In Tables VI, VII, VIII, and IX the results of these experiments are given. The weight of the untreated plants, or checks, is taken as 100; and the weights of the plants grown under similar conditions, but in soils treated with various potash and phosphatic fertilizers, are compared with this figure.

TABLE VI.—*Relative green weights of wheat plants grown for a period of three weeks in Carrington silt loam untreated and treated with various quantities of potassic and phosphatic fertilizers.*

Treatment.	Application per acre.		Relative green weights.	Average.
	K_2O.	P_2O_5.		
	Pounds.	*Pounds.*		
Check			100	100
Slag (33SB)	50	60	101	
Do	100	120	104	104
Do	200	240	107	
Potassium sulphate	50		100	
Do	100		113	106
Do	200		106	
Acid phosphate		60	101	
Do		120	107	107
Do		240	114	
Potassium sulphate and acid phosphate	50	60	110	
Do	100	120	110	109
Do	200	240	108	

TABLE VII.—*Relative green weights of wheat plants grown for a period of three weeks in Hagerstown loam untreated and treated with various quantities of potassic and phosphatic fertilizers.*

Treatment.	Application per acre.		Relative green weights.	Average.
	K_2O.	P_2O_5.		
	Pounds.	*Pounds.*		
Check			100	100
Slag (33SB)	50	60	101	105
Do	100	120	107	
Do	200	240	106	
Potassium sulphate	50		122	127
Do	100		129	
Do	200		130	
Acid phosphate		60	101	101
Do		120	102	
Do		240	101	
Potassium sulphate and acid phosphate	50	60	111	121
Do	100	120	116	
Do	200	240	136	

TABLE VIII.—*Relative green weights of wheat plant grown for a period of three weeks in Volusia silt loam, untreated and treated with various quantities of potassic and phosphatic fertilizers.*

Treatment.	Application per acre.		Relative green weights.	Average.
	K_2O.	P_2O_5.		
	Pounds.	*Pounds.*		
Check			100	100
Slag (33SB)	50	60	113	112
Do	100	120	114	
Do	200	240	109	
Potassium sulphate	50		124	116
Do	100		117	
Do	200		107	
Acid phosphate		60	109	117
Do		120	113	
Do		240	128	
Potassium sulphate and acid phosphate	50	60	116	115
Do	100	120	119	
Do	200	240	109	

TABLE IX.—*Relative green weights of wheat plants grown for a period of three weeks in limed Volusia silt loam, untreated and treated with various quantities of potassic and phosphatic fertilizers.*

Treatment.	Application per acre.		Relative green weights.	Average.
	K_2O.	P_2O_5.		
	Pounds.	*Pounds.*		
Check			100	100
Slag (33SB)	50	60	104	116
Do	100	120	110	
Do	200	240	135	
Potassium sulphate	50		99	114
Do	100		142	
Do	200		100	
Acid phosphate		60	129	123
Do		120	124	
Do		240	116	
Potassium sulphate and acid phosphate	50	60	110	110
Do	100	120	118	
Do	200	240	103	

Tables VI, VII, VIII, and IX show that in every case applications of the slag fertilizer to the soils had a stimulating and beneficial effect.

The increase in growth caused by the citric soluble potash and phosphoric acid in the slag was, as a rule, less than that caused by the application of the equivalent quantities of these two fertilizer elements in a water-soluble form, but this is to be expected in the case of experiments carried on for such a short period of time. The tests, of course, are not conclusive, but they indicate that good results may be expected from the use of such a fertilizer.

SUMMARY.

A method of obtaining both potash and phosphoric acid in citric soluble form has been devised. It consists of mixing together phosphate rock and feldspar with the addition of small quantities of the oxides of iron and manganese to promote fluidity or lower the melting point of the slag, the mass being then heated to about 1,400° C. for about 20 minutes. The resulting product is not only soluble in a 2 per cent citric acid solution, but is also fairly soluble in water saturated with carbon dioxide. Pot tests with typical soils showed that the mineral increased the growth of wheat plants, but the beneficial effect derived from such applications was not, on the whole, as marked as it was when more soluble forms of phosphate and potash were used. The indications are, however, that the slag product has a distinct high fertilizer value.

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No. 144

Contribution from the Bureau of Soils, Milton Whitney, Chief.
December 24, 1914.

THE MANUFACTURE OF ACID PHOSPHATE.

By Wm. H. Waggaman, *Scientist in Fertilizer Investigations.*

INTRODUCTION.

The acid-phosphate industry in the United States has grown to enormous proportions. In spite of the fact that numerous other forms of phosphatic fertilizer have been proposed or patented from time to time, and the application of raw ground-rock phosphates directly to the field has been recommended by some agronomists and agricultural chemists, the annual production of superphosphate continues to increase There is little doubt, therefore, that this material will continue to be the basis of most of our commercial fertilizers.

While the general procedure followed in making acid phosphate is a familiar one, many of those engaged in the production of this material have but little knowledge of the chemistry involved and are unfamiliar with numerous details of its manufacture, which are of great economic importance.[1] Competition has become so keen in the fertilizer industry during the last few years that in order to make a reasonable profit the manufacturer can no longer afford to carry on his business in the loose way formerly so prevalent, but must practice the most modern scientific methods and exercise the closest supervision over every detail of his factory processes. It is believed that the preparation of this bulletin is justified by the information it will furnish the fertilizer manufacturers; but it is intended primarily to give the progressive farmer a clearer knowledge of that compound which is the basis of fertilizers, in order that he may more intelligently buy and handle his fertilizer and determine for himself its true value. Such knowledge, it is believed, should tend greatly to clarify prevailing ideas concerning the value of factory and of home-mixed fertilizers, and to throw light on the attendant question of inordinate profits alleged to be made by manufacturers. This paper describes

[1] Brogdon, J. S., Manufacture of Acid Phosphate. Amer. Fertilizer, **39** (5), pp. 25-29 (1913).

Note.—Describes the manufacture of acid phosphate from phosphate rock, detailing the chemical and mechanical changes involved. Of interest to fertilizer manufacturers generally.

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the whole process, including the preparation of the raw materials used, the methods of manufacture with the chemical reactions involved, the equipment of the modern factory, the disposal of obnoxious gases, the methods of drying, storing, and disintegrating the superphosphate, and the cost and disposal of the finished product.

RAW MATERIALS.

The raw materials used in the manufacture of acid phosphate are bone, guano, apatite, phosphate rock, and sulphuric acid.

Before the discovery of the vast deposits of phosphorites or natural phosphate rock in this country bone was one of the farmer's chief sources of phosphoric acid. The bones were either steamed, charred, or burned and applied directly to the field, or after grinding were made into acid phosphate by treating with an approximately equal weight of sulphuric acid.

Ground bone, however, has considerable agricultural value without being acidulated, and besides, the cost of the phosphoric acid contained therein is so much greater than that contained in phosphate rock that it is obviously not economical to use the former material in the manufacture of acid phosphate. The amount of this substance now derived from bone is therefore relatively small.

Guano is another substance which has been extensively used in the manufacture of acid phosphate. This material consists essentially of the excrements of birds and sometimes of bats, and at one time was found in large quantities. There are two types of guano deposits: (1) The unleached deposits which are usually found in caves or other sheltered places where the droppings have been protected from the leaching effect of percolating water. Such a deposit not only contains phosphoric acid in a readily available form, but also carries considerable quantities of nitrogen, the fertilizer constituent commanding the highest price. (2) That which has been leached of its more soluble constituents by exposure to the weather. It contains practically no nitrogen and its phosphoric-acid content, though usually high, is relatively insoluble. Deposits of guano have been eagerly sought, and accessible and valuable ones are now rather scarce. Only those containing high percentages of nitrogen, or situated in regions having excellent transportation facilities, are able to compete with other and cheaper sources of phosphate.

At one time apatite was largely used in the manufacture of acid phosphate. This mineral is very widely distributed, and occurs in rocks of various kinds and ages. It is most common, however, in rocks of the metamorphic crystalline variety, such as limestone, gneiss, mica, schist, beds of iron ore, etc. There are two main varieties of apatite, namely, chlor-apatite ($CaClCa_4P_3O_{12}$) and fluor-apatite ($CaFCa_4P_3O_{12}$). The latter variety is by far the most common, but there are intermediate compounds containing both chlorine and fluorine. Pure fluor-apatite contains 42.3 per cent phosphoric acid (P_2O_5), but it is seldom found in a pure condition. The occurrence of apatite associated with magnetite in northern New York [1] has long been known, but attempts to separate the apatite commercially have proved unsuccessful.

In Norway and Canada, however, there are large deposits of apatite which were at one time extensively worked, but the discovery of cheaper and more accessible sources of phosphoric acid (particularly in the United States) has caused a serious curtailment in the mining of this mineral.

The main objections to apatite as a source of phosphoric acid are, first, the expense of mining and picking the rock and, second, the large percentage of fluorine, which yields obnoxious gases when the rock is treated with sulphuric acid. The superphosphate now manufactured from apatite is but a small percentage of the total material marketed.

The vast bulk of acid phosphate produced both in this country and abroad is made from the amorphous phosphates of lime, of which there are enormous deposits in the States of Florida, Tennessee, Utah, Idaho, Wyoming, and Montana, and in northern Africa, and smaller deposits in the States of South Carolina, Arkansas, and Kentucky in this country, and in France, Germany, England, and Belgium.

Ocean and Pleasant Islands of the Gilbert group, as well as some of the Society Islands in the southern Pacific and Christmas Island in the Indian Ocean, contain large quantities of very high grade phosphate rock; in fact, these phosphates are as rich as any amorphous phosphates known. It is only in recent years, however, that the deposits have been developed to any extent, and owing to the lack of harbors the rock must be loaded at sea, which makes their exploitation somewhat difficult.

The character of the American deposits, the methods of mining and preparing the rock for the market, the cost of production, annual output, and other details of this industry have been described in bulletins of this department,[2] and so need not be repeated here.

In Table I is given a list of the more important phosphatic substances (with their approximate composition) used in the manufacture of acid phosphate.

[1] Blake, W. P., Trans. Am. Inst. Min. Engrs., **21**, pp. 157–160 (1892–93).

[2] Buls. 41, 69, 76, and 81, Bureau of Soils, U. S. Dept. Agr.; Bul. 14, U. S. Dept. Agr. (1913).

TABLE I.—*Composition of phosphatic materials used in the manufacture of acid phosphate.*

Phosphatic material.	Location.	Nitrogen (N).	Silica or insoluble (SiO_2).	Oxide of iron and aluminum (Fe_2O_3), (Al_2O_3).	Calcium fluoride (CaF_2).	Carbonate of lime ($CaCO_3$).	Phosphoric acid (P_2O_5).	Tricalcium phosphate[1] $Ca_3(PO_4)_2$.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Bone ash		4.06	3.01			5.28	35.38	76.65
Fat-extracted bone.		4.14	3.60			5.24	21.68	46.50
Bone or animal charcoal.		1.12	2.00	0.37	1.00	8.00	31.99	73.10
Apatite:								
High grade	Canada		3.67	.70	3.10	4.13	38.60	88.20
Lower grade	do		8.92	1.03	3.04	8.05	34.42	78.65
Apatite (high grade).	Norway		3.62	1.37	2.62	.29	39.44	86.10
Bat guano	Porto Rico	8.35		1.59			7.57	16.52
Guano in crusts	West Indies	.45		5.88			24.36	53.18
Phospho-guano	Mexico	.40		1.14			39.70	86.66
Phosphorite:								
High grade	Somme, France		.79	1.39		9.17	35.59	77.69
Lower grade	do		8.55	4.07		6.95	29.10	63.53
Do	Liege, Belgium		16.14	2.39	5.00	7.07	27.20	62.15
Coprolites	Cambridge, Eng.		9.00			2.30	34.00	77.70
Do	Suffolk, Eng		Not det.	9.00	6.00	10.00	23.63	54.00
Phosphate nodules.	Russia		Not det.	5.00	6.98	12.23	32.82	75.00
Do	South Carolina		4 to 12	1 to 4	2 to 8	11 to 25	25 to 28	57 to 64
Hard rock phosphate.	Florida		4.13	3.00	4.40	3.63	36.39	83.14
Land pebble phosphate.	do		5 to 10	1 to 4	0 to 3	2 to 5	30 to 34	69 to 78
Brown rock phosphate.	Tennessee		2.5 to 10	3 to 8	0 to 5	0 to 10	30 to 38	69 to 87
Blue rock phosphate.	do		2.5 to 70	2.5 to 7	0 to 3	0 to 2	27 to 32	62 to 73
White rock phosphate.	do		2 to 7.5	1.5 to 3.5			32 to 38	73 to 87
Black rock phosphate.	Arkansas		15 to 40	2.5 to 9.5			23 to 28	53 to 64
Brown rock phosphate.	Kentucky		2 to 5	2.5 to 5			30 to 35	69 to 80
Oolitic black phosphate.	Utah, Idaho, etc.		1.8 to 10	.07 to 1.6	.8 to 1.35	3.8 to 13.6	27 to 36.5	62 to 83
White phosphate	Ocean Islands		Not det.	.42	1.0	4.91	38.73	84.65

[1] Known to the trade as bone phosphate of lime, b. p. l.

The sulphuric acid used in the manufacture of acid phosphate is the ordinary "chamber acid." It ranges in specific gravity from 1.5 to 1.6 at 60° F. and contains from 60 to 70 per cent of sulphuric acid. The fertilizer trade, however, is accustomed to expressing the strength of "chamber acid" in Baumé degrees (°B). The manufacturer should have conversion tables at hand showing the specific gravity and percentage of acid corresponding to each degree registered by the Baumé hydrometer. Part of such a table approved and adopted by the Manufacturing Chemists Association of the United States is given in Table II.

TABLE II.—*Specific gravities and their equivalents in Baumé degrees of sulphuric acid of various strengths.*

°B.	Sp. gr.	Per cent H_2SO_4.	°B.	Sp. gr.	Per cent H_2SO_4.	°B.	Sp. gr.	Per cent H_2SO_4.
0	1.0000	0.00	25	1.2083	28.28	49	1.5104	60.75
1	1.0069	1.02	26	1.2185	29.53	50	1.5263	62.18
2	1.0140	2.08	27	1.2288	30.79	51	1.5426	63.66
3	1.0211	3.13	28	1.2393	32.05	52	1.5591	65.13
4	1.0284	4.21	29	1.2500	33.33	53	1.5761	66.63
5	1.0357	5.28	30	1.2609	34.63	54	1.5934	68.13
6	1.0432	6.37	31	1.2719	35.93	55	1.6111	69.65
7	1.0507	7.45	32	1.2832	37.26	56	1.6292	71.17
8	1.0584	8.55	33	1.2946	38.58	57	1.6477	72.75
9	1.0662	9.66	34	1.3063	39.92	58	1.6667	74.36
10	1.0741	10.77	35	1.3182	41.27	59	1.6860	75.99
11	1.0821	11.89	36	1.3303	42.63	60	1.7059	77.67
12	1.0902	13.01	37	1.3426	43.99	61	1.7262	79.43
13	1.0985	14.13	38	1.3551	45.35	62	1.7470	81.30
14	1.1069	15.25	39	1.3679	46.72	63	1.7683	83.34
15	1.1154	16.38	40	1.3810	48.10	64	1.7901	85.66
16	1.1240	17.53	41	1.3942	49.47	$64\frac{1}{4}$	1.7957	86.33
17	1.1328	18.71	42	1.4078	50.87	$64\frac{1}{2}$	1.8012	87.04
18	1.1417	19.89	43	1.4216	52.26	$64\frac{3}{4}$	1.8068	87.81
19	1.1508	21.07	44	1.4356	53.66	65	1.8125	88.65
20	1.1600	22.25	45	1.4500	55.07	$65\frac{1}{4}$	1.8182	89.55
21	1.1694	23.43	46	1.4646	56.48	$65\frac{1}{2}$	1.8239	90.60
22	1.1789	24.61	47	1.4796	57.90	$65\frac{3}{4}$	1.8297	91.80
23	1.1885	25.81	48	1.4948	59.32	66	1.8354	93.19
24	1.1983	27.03						

THEORETICAL BASIS FOR THE MANUFACTURE OF ACID PHOSPHATES.

The process of making acid phosphate was devised in order to change the phosphoric acid contained in the substances just enumerated into a more soluble or "available" condition.

The phosphates of lime, as found in nature are highly basic compounds or solid solutions offering considerable resistance to the solvent influence of percolating meteoric or soil waters. The less basic phosphates (those containing less lime, iron, alumina, or magnesia) are more soluble in water.[1] Therefore, in order to bring about the desired change, an acid stronger than phosphoric acid is added in sufficient quantity to combine with a portion of the lime, producing a phosphate less basic and, consequently, more soluble. The reagent which has been found best suited for this purpose is sulphuric acid, not only because of its cheapness but because calcium sulphate, one of the products of the reaction, takes up the excess of water present in the acid phosphate to form gypsum. The final product, therefore, if properly made, is dry and can be readily mixed with other ingredients to make a complete fertilizer.

The main purpose sought to be accomplished in the factory treatment of phosphate rock is to prepare a product in which the phosphoric acid will be water soluble, so far as this can be accomplished, with due regard to the physical properties of the product essential to its ready mixing and handling. While it is a matter of no great difficulty to determine by a chemical analysis just what constituents are in a given phosphate rock and in what proportions, it is not

[1] Bul. 41, Bureau of Soils, U. S Dept. Agr. (1907).

known just how these constituents are chemically united. It is generally assumed that the phosphoric acid is combined with the lime in a hypothetical compound—tricalcium phosphate (known to the trade as bone phosphate of lime, b. p. l.), represented by the formula $Ca_3(PO_4)_2$, and that this compound, when treated with sulphuric acid (H_2SO_4) and water (H_2O) in the right proportions, is converted into a mixture of gypsum ($CaSO_4.2H_2O$) and monocalcium phosphate [$Ca(H_2PO_4)_2$]. Both gypsum and monocalcium phosphate are perfectly definite, well-known compounds. The former is but slightly soluble, the latter readily soluble in water. As a matter of fact, in the reaction cited above, it is probable that dicalcium phosphate [$Ca(HPO_4)_2$] is formed as well. Both these calcium phosphates are decomposed by water, so that a solution of monocalcium phosphate, if diluted, will precipitate dicalcium phosphate and if the dilution be carried further, a phosphate even more basic than the tricalcium phosphate is formed.[1] Obviously, the more basic the calcium phosphate, the less soluble it is in water. It is equally obvious that when incorporated in the soils, the soil water, while dissolving and distributing the phosphate, is at the same time decomposing it into less soluble forms. Assuming now, as we may do for convenience, that the reaction takes place in the mixing as outlined above, it may be represented thus:

Tricalcium phosphate or pure phosphate rock.		Sulphuric acid.		Water.	
$Ca_3(PO_4)_2$	+	$2H_2SO_4$	+	$4H_2O$	=
1 molecule, weight 310.		2 molecules, weight 196.		4 molecules, weight 72.	

Gypsum.		Monocalcium phosphate or superphosphate.
$2(CaSO_4\ 2H_2O)$	+	$CaH_4(PO_4)_2$.
2 molecules, weight 344.		1 molecule, weight 234.

The above equation means that in order to change completely 310 parts of tricalcium phosphate or pure phosphate rock into acid phosphate, 196 parts of *pure* sulphuric acid are required, or 1 ton of phosphate rock requires 0.63 ton of sulphuric acid. Factory practice and long experience in the manufacture of acid phosphate have shown, however, that much better results are obtained by employing sulphuric acid containing from 30.35 to 37.82 per cent of water ("chamber acid"). A part of the water contained in this acid is evaporated by the heat of the chemical reactions taking place, and a part is taken up by the calcium sulphate formed to produce gypsum, as shown in the above equation.

IMPURITIES IN PHOSPHATE ROCK.

Besides calcium phosphate the phosphates of commerce always contain varying quantities of impurities, such as organic matter, silica or silicates, calcium fluoride, oxides or phosphates of iron and

[1] Vide, Bul. 41, Bureau of Soils, U. S. Dept. Agr., pp. 22–25 (1907).

aluminum, and carbonates of lime or magnesia. All of these impurities take up or are acted upon directly or indirectly by sulphuric acid, the bases being converted into sulphates and the fluorides, carbonates, and organic matter being decomposed with the evolution of gases. It is very important that the manufacturer should be acquainted with the effect that these impurities and the compounds produced therefrom will have upon his acid phosphate, and he should be able to calculate from the analysis of his raw material what quantity and strength of sulphuric acid is required to satisfy these impurities. The action of the sulphuric acid upon the various foreign substances found in natural phosphates of lime, and the effect of these impurities on the finished product are discussed below in some detail.

ORGANIC MATTER.

Practically all phosphates, with the exception of apatite, are of animal origin and therefore contain a certain amount of organic matter. When present in any quantity organic matter usually imparts a dark color to the phosphate. The presence of very small quantities can be detected by the putrid odor emitted on crushing or grinding the rock. The phosphates of our western States, as well as some of the Tennessee rock, contain considerable quantities of organic matter, while most of the Florida phosphates are very low in this material.

The methods now employed in drying phosphate, either by calcining it on ricks of wood or putting it through a rotary drier, burns out or destroys a part of the organic matter; the remainder is carbonized by sulphuric acid with the evolution of volatile or gaseous products. The sulphuric acid is at the same time reduced to sulphur dioxide (SO_2), or to hydrogen sulphide (4_2S) if the reduction has proceeded further. The production of these gases not only entails a loss of sulphuric acid, but they are both disagreeable and deleterious to health.

In making acid phosphate the organic matter found in the rock is not considered, since the amount present is usually small. Owing to the various forms in which organic matter may occur, it is almost impossible to judge except by actual experiment how much sulphuric acid is required for its decomposition.

SILICA AND SILICATES.

Sulphuric acid has no direct action upon silica (SiO_2), but when fluorides are present an indirect action occurs, which is described below. Silicates are directly acted upon by sulphuric acid, but so slowly that they need hardly be taken into account. The presence of silica or silicate minerals in phosphate rock is not considered objectionable except in so far as they act as diluents. Phosphates containing high percentages of silica necessarily have a lower percentage of phosphoric acid than the less siliceous or purer phosphates.

CALCIUM FLUORIDE.

Fluorides are present in almost all phosphate rock. Some samples contain as high as 8 per cent of calcium fluoride (CaF_2). The amorphous phosphates as a rule contain smaller quantities of this compound than apatite.

Calcium fluoride reacts with sulphuric acid, giving gaseous hydrofluoric acid (HF) and calcium sulphate, thus:

$$\begin{array}{ccccccc} \text{Calcium fluoride.} & & \text{Sulphuric acid.} & & \text{Hydrofluoric acid.} & & \text{Calcium sulphate.} \\ CaF_2 & + & H_2SO_4 & = & 2HF & + & CaSO_4 \end{array}$$

But hydrofluoric acid (HF) acts upon the silica or silicates present in the mass, producing gaseous silicon, tetrafluoride (SiF_4), and water or steam, thus:

$$\begin{array}{ccccccc} \text{Hydrofluoric acid.} & & \text{Silica.} & & \text{Silicon tetrafluoride.} & & \text{Water.} \\ 4HF & + & SiO_2 & = & SiF_4 & + & 2H_2O \end{array}$$

Silicon tetrafluoride in turn is decomposed by water with the formation of hydrofluosilicic acid (H_2SiF_6) and precipitation of pure silica (SiO_2), thus:

$$\begin{array}{ccccccc} \text{Silicon tetrafluoride.} & & \text{Water or steam.} & & \text{Hydrofluosilicic acid.} & & \text{Silica.} \\ 3SiF_4 & + & 2H_2O & = & 2H_2SiF_6 & + & SiO_2 \end{array}$$

Before this last reaction takes place, however, much of the silicon tetrafluoride escapes from the mass and can be detected by its penetrating odor and smarting effect on the eyes and nose.

Very high grade acid phosphate can be made from rock containing large amounts of fluorine, because, as pointed out above, many of the products formed during the process escape as gases or vapors, leaving the mass correspondingly richer in phosphoric acid. These gases also, in forcing their way out of the acid phosphate, tend to render it porous and more readily dried. The product, therefore, can be easily broken up and mixed with other ingredients to make a complete fertilizer.

The main objections to using phosphates high in fluorides are, first, the increased quantity of sulphuric acid necessary to decompose these compounds, and, second, the noxious and even poisonous nature of the gases evolved during their decomposition.

COMPOUNDS OF IRON AND ALUMINUM.

Iron and aluminum oxides, either in the free state or combined as phosphates, are the most objectionable of the impurities found in phosphate rock. These substances even when present in very small quantities cause a certain amount of "reversion" in the superphosphate, and when present in large quantities are likely to produce a sticky acid phosphate unfit for commercial purposes.

The phosphate of iron in natural occurrences may conveniently be represented by the formula $FePO_4$, although actually it is probably of an indefinite composition. The exact reactions that take place when this substance is treated with sulphuric acid are not known. Unquestionably, however, the iron is distributed between the two acids. A mixture of "sticky," disagreeable physical properties results, the composition of the solid part of the mixture changing with the composition of the liquid part which is formed at the same time. Both the solid and the liquid contain all three constituents—iron, sulphuric acid, and phosphoric acid. Dilution of this liquid mass by the addition of water causes a precipitation of more jellylike material containing relatively more iron and phosphoric acid than sulphuric acid. The general course of the reactions are sufficiently well known to justify the assumption that they go mainly according to the following equations:

$$2FePO_4 + 3H_2SO_4 \leftrightarrows Fe_2(SO_4)_3 + 2H_3PO_4$$

But a part of the iron sulphate produced reacts with the phosphoric acid or monocalcium phosphate in the mass forming hydrated phosphate of iron, the gelatinous precipitate almost insoluble in water, and when present in any quantity causing the acid phosphate to be sticky and difficult to handle. The reactions may be represented thus:

Iron sulphate.		Phosphoric acid.		Water or steam.		Hydrated iron phosphate		Sulphuric acid.
$Fe_2(SO_4)_3$	+	$2H_3PO_4$	+	$4H_2O$	$\rightleftarrows$	$2FePO_4.2H_2O$	+	$3H_2SO4$

According to Fritsch,[1] however, two per cent of iron oxide in the raw material is not objectionable, because the quantity of iron sulphate produced therefrom remains unaltered in the superphosphate. It is true that in properly made acid phosphate nearly all of the phosphoric acid is soluble in water even though there is sufficient iron present to cause part of it to revert, but Fritsch is probably in error in attributing this to the fact that the iron is all in the form of sulphate. Schneider[2] has shown experimentally that solutions of sulphate of iron increase the solubility of iron phosphate and Cameron and Bell[3] have demonstrated that gypsum, lime, and phosphoric acid also increase the solubility of this substance.

Hydrated iron phosphate may be converted into the anhydrous and less soluble condition by reacting with anhydrous calcium sulphate; the last-named compound being converted into gypsum, thus:

Hydrated iron phosphate.		Anhydrous calcium sulphate.		Gypsum.		Anhydrous iron phosphate.
$FePO_4\ 2H_2O$	+	$CaSO_4$	$\rightleftarrows$	$=CaSO_4.2H_2O$	+	$FePO_4$.

[1] Manufacture of Chemical Manures, pp. 78–79 (1911).
[2] Zeit. anorg. Chem., **5**, 84; **7**, 386 (1894).
[3] Bul. 41, Bureau of Soils, U. S. Dept. Agr. (1907).

This last reaction partly explains why acid phosphate in excellent mechanical condition, but with a relatively high percentage of phosphoric acid insoluble in water is often made from rock containing large quantities of iron and aluminum.

Compounds of aluminum react in a manner similar to those of iron, but to a less marked degree.

Fertilizer manufacturers and authorities differ widely on the question of what constitutes the maximum quantity of iron and alumina that a phosphate rock can contain and still be useful in the manufacture of acid phosphate. Wyatt[1] says that phosphates containing from 6 to 8 per cent of iron and alumina may be used, provided there is sufficient carbonate of lime present to produce a dry, pulverulent mass. Schucht[2] and Fritsch[3] are inclined to consider any quantity of iron and alumina in excess of 3 per cent as undesirable. Stillwell[4] states that phosphates containing from 4 to 6 per cent of these oxides can be handled, but that the presence of more than 2 per cent is objectionable.

Thousands of tons of high-grade acid phosphate, however, are now annually made from Tennessee brown rock phosphate containing as high as 5 per cent of the combined oxides of iron and aluminum, and though the handling of such phosphates necessitates an increased consumption of sulphuric acid, there seems little reason why they should not be used in making acid phosphate, provided they are so manipulated that a dry, readily workable product is obtained.

CARBONATES OF LIME AND MAGNESIA.

Carbonates are frequently very desirable impurities in phosphate rock, provided they do not occur in quantities so great that the percentage of phosphoric acid present is materially reduced. The carbonic acid is usually combined with lime, and it is in this form that it is considered here. Sulphuric acid acts upon calcium carbonate to form calcium sulphate, water or steam, and carbon dioxide, which escapes as a gas. The reaction may be represented thus.

Sulphuric acid.		Calcium carbonate.		Calcium sulphate.		Water or steam.		Carbon dioxide.
H_2SO_4	+	$CaCO_3$	=	$CaSO_4$	+	H_2O	+	CO_2

If sufficiently diluted sulphuric acid is used the excess of water combines with the calcium sulphate to form gypsum. Modifying the above equation therefore, we obtain:

Sulphuric Acid.		Water.		Calcium carbonate		Gypsum.		Carbon dioxide.
H_2SO_4	+	H_2O	+	$CaCO_3$	=	$CaSO_4.2H_2O$	+	CO_2

[1] Phosphates of America, pp. 111–116 (1891).
[2] Die Fabrikation des Superphosphates, pp. 79–83 (1909).
[3] Manufacture of Chemical Manures, pp. 78–80 (1911).
[4] Industrial Chemistry, Rogers & Aubert, p. 403 (1912).

The advantages of having small quantities (and in some cases large quantities) of carbonate of lime present in phosphate rock are threefold: First, the heat evolved in the reaction between carbonates and sulphuric acid is sufficient to warm the pasty mass of acid and phosphate rock and thus promote chemical action between these more slowing reacting substances; second, the escape of carbon dioxide from the mass renders the acid phosphate porous and more readily dried; and third, the gypsum formed prevents the formation of the gelatinous iron and aluminum compounds and thus helps render the product dry and in good condition for distributing or mixing with other fertilizing ingredients.

REVERSION OF SUPERPHOSPHATE.

The reversion of superphosphate, as the term implies, originally meant the return of the phosphoric acid to a condition insoluble (or nearly so) in water. In reality the expression "reverted" phosphoric acid is now wrongly used in a much broader sense and includes all of the phosphoric acid of superphosphate which is soluble in certain citrate solutions. In this paper, however, reverted phosphoric acid is used in the strict sense of the word.

When a superphosphate is allowed to stand and take up water from moist air, as it sometimes does while in storage; or is diluted by the soil water when it is applied to the soil; or is added to an excess of water, as is done in the laboratory before commencing analytical operations, then, in any one and in all of these cases, less soluble compounds of phosphoric acid are formed. If compounds of iron and aluminum are present the formation of phosphates insoluble in water is much more marked. This general process is known as *reversion*, and the superphosphate is said to have *reverted*, and the product is called *reverted phosphate*. The theory of this reversion is now clearly understood, owing to the investigations in this country of Cameron and Bell [1] and Seidell,[2] and of Bassett [3] in England, who have shown that certain concentrations of phosphoric acid or of other acids must exist in the water in contact with a calcium or iron phosphate for the solid definite "acid" compounds to be stable. Dilution of the acid liquor causes the solids to decompose into more basic and less soluble compounds. While the theory of these phenomena has been made clear only recently, the main facts have long been known, and as is so commonly the case, certain popular misconceptions have held sway long enough to become regarded as facts even by many well-trained chemists. Thus, it is popularly held that monocalcium phosphate is soluble in water, but dicalcium phosphate is not; dicalcium

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[1] Bul. 41, Bureau of Soils, U. S. Dept. Agr. (1907).

[2] Jour. Am. Chem. Soc., **27**, 1503 (1905).

[3] Chem. News, **95**, 21 (1907); Zeit. anorg. Chem., **53**, 34 (1907).

phosphate is in turn soluble in certain citrate solutions, while tricalcium phosphate is not; and on these supposed facts methods for separating the three compounds have been suggested. Moreover, it is held that while the water-soluble monocalcium phosphate and citrate soluble dicalcium phosphate are "available" to plants, more basic phosphates are not.

The facts are that the presence of citric acid or ammonium citrate in the water does increase the solubility of the phosphates of lime, iron, and alumina, and it has been shown by field tests that phosphates soluble in such solutions are more quickly active under soil conditions than those which do not dissolve in the same mediums. Hence a convenient control or "police" method of analyzing commercial fertilizer containing phosphates has been developed. But the "citrate solubility" gives no definite information about the constitution of the phosphate. The actual phenomena involved in *reversion* can be best followed by the microscope.

Reversion is, however, a reality, and one to be carefully avoided. The reverted phosphate is frequently difficult to handle, and even if its mechanical condition is good and the phosphoric acid present is classed as available according to the official method of analysis, many consumers seriously object to its use because the percentage of water soluble phosphoric acid present is relatively low. Moreover, reverted phosphate is not easily susceptible to retreatment in the factory, and usually the manufacturer can better afford to throw it away than attempt to work it over in competition with untreated raw rock.

METHOD OF MANUFACTURE.

GRINDING THE ROCK.

The phosphate rock is first put through a crusher and broken in pieces not larger than a walnut. This crushing is hardly necessary in the case of Florida pebble phosphate or the screenings from the hard rock phosphate, since the pebbles and fragments are usually small enough to be fed directly to the mill.

The pulverizers for phosphate rock that are probably most widely used in this country are those of the roller type, in which the material is crushed by steel rollers revolving within a steel ring. Sometimes the ring within which these rollers revolve is rigid and the power is transmitted through the rollers. In another form of mill, the ring is revolved by a shaft, and the rollers are revolved in turn by the ring.

There are a number of different makes of these pulverizers, but space does not permit a detailed explanation of their construction. For convenience they all may be placed in one of two broad classes, namely, the type which combines both grinding machinery and screens in one, and the type which discharges the partly ground material into elevators to be subsequently screened or separated, the coarser material being returned to the mill for further grinding.

Mills of the first type occupy but little space, do not require auxiliary screens and conveyors, and the grinding is all finished in one operation. The fact, however, that the pulverized phosphate is not separated from the coarser rock until forced through the screens within the mill cuts down somewhat the efficiency of this type of machine, since considerable space and power is always taken up by material already ground. Another disadvantage of this type of mill is that any clogging of the screens or break in the same necessitates the shutting down of the entire mill while the damage is repaired. The manufacturers of the o her type of mill claim to have overcome these disadvantages in their machines; the ground material is continually discharged from the mill and separated from the coarser rock by passing through revolving, or over vibrating screens. Any trouble with a screen can be corrected without stopping the mill by simply cutting off the supply of rock to that screen. Since the material flows over the screens instead of being forced against them as in the case of the other type of mill, the repairs necessary on the screens are reduced to a minimum. This type of mill, however, with its auxiliary screens and conveyors, takes up considerable space, costs more to install, and requires a greater amount of supervision. In Plates I and II these two types of roller mills are shown.

The amount of material which can be pulverized per hour depends on the size of the mill, the character of the phosphate rock used, and the degree of fineness to which it is ground. A mill of the size usually employed in fertilizer factories may grind from 10 to 12 tons per hour of Tennessee brown rock phosphate to pass a 60-mesh sieve, but this mill will probably not grind more than seven or eight tons of pebble phosphate to the same degree of fineness in that period of time.

A very ingenious ball mill is that of Pfeiffer.[1] The grinding is done by means of steel balls or flint pebbles and the separation of the fine material from the coarse is effected by means of a current of air. All loss of time due to the clogging and repairing of screens is thus avoided and a product of any degree of fineness can be obtained by simply regulating the strength of the air current.

The degree of fineness to which phosphate rock is ground often has a very important effect on the acid phosphate produced therefrom. Phosphate rocks low in carbonates and high in iron and aluminum are but slowly acted upon by sulphuric acid, and should therefore be gound very fine. Phosphates containing large quantities of carbonate of lime are acted upon quite rapidly, and consequently do not require extremely fine grinding. In ordinary practice the rock is usually ground so that 80 to 90 per cent will pass a 60-mesh sieve, but in working with less soluble phosphates it is frequently desirable to grind them so that 80 to 85 per cent will pass an 80-mesh sieve.

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[1] German patent No. 116,195.

QUANTITY, STRENGTH, AND TEMPERATURE OF SULPHURIC ACID.

The quantity and strength of sulphuric acid which should be used in treating phosphate rock is a perplexing problem, yet many manufacturers give it little consideration, proceeding in a "rule of thumb" manner without regard to the composition of the rock. The reason why many of these latter obtain such good results may be explained by the fact that they have been using one grade of rock for years and have thus learned by actual experience the proper proportions of acid and rock to use. A sudden change in the composition and grade of the phosphates often results in a loss of both acid and rock in attempts to find the quantity of acid required for this new material. While actual trial mixings should be made when testing out a new grade of phosphate, these tests should be intelligently conducted with due regard to the composition of this rock. Take, for example, a sample of high-grade Florida hard rock phosphate having the following composition:

	Per cent.
Moisture	0.5
Calcium fluoride (CaF_2)	4.5
Tricalcium phosphate ($Ca_3(PO_4)_2$)	80.0
Calcium carbonate ($CaCO_3$)	3.5
Aluminum phosphate ($AlPO_4$)	6.0
Silica (SiO_2)	5.5
Total	100.0

The problem is to convert the phosphoric acid of this rock into a soluble form and yet obtain a dry product which can be uniformly spread on the soil or readily mixed with other ingredients to make up a complete fertilizer. The reactions which are desired may be represented in their simplest form, thus:

(1) Conversion of tricalcium phosphate to monocalcium phosphate and calcium sulphate:

$$\begin{array}{ccccccc} \text{1 molecule} & & \text{2 molecules} & & \text{1 molecule} & & \text{2 molecules} \\ Ca_3(PO_4)_2 & + & 2H_2SO_4 & = & CaH_4(PO_4)_2 & + & 2CaSO_4 \\ \text{Wt. 310} & & \text{Wt. 196} & & \text{Wt. 234} & & \text{Wt. 272} \end{array}$$

(2) Conversion of calcium fluoride to hydrofluoric acid and calcium sulphate:

$$\begin{array}{ccccccc} \text{1 molecule} & & \text{1 molecule} & & \text{2 molecules} & & \text{1 molecule} \\ CaF_2 & + & H_2SO_4 & = & 2HF & + & CaSO_4 \\ \text{Wt. 78} & & \text{Wt. 98} & & \text{Wt. 40} & & \text{Wt. 136} \end{array}$$

(3) Conversion of iron phosphate to iron sulphate and phosphoric acid:

$$\begin{array}{ccccccc} \text{2 molecules} & & \text{3 molecules} & & \text{1 molecule} & & \text{2 molecules} \\ 2FePO_4 & + & 3H_2SO_4 & = & Fe_2(SO_4)_3 & + & 2H_3(PO_4) \\ \text{Wt. 302} & & \text{Wt. 294} & & \text{Wt. 400} & & \text{Wt. 196} \end{array}$$

(4) Conversion of aluminum phosphate to aluminum sulphate and phosphoric acid:

$$\begin{array}{ccccccc} \text{2 molecules} & & \text{3 molecules} & & \text{1 molecule} & & \text{2 molecules} \\ 2AlPO_4 & + & 3H_2SO_4 & = & Al_2(SO_4)_3 & + & 2H_3PO_2 \\ \text{Wt. 245} & & \text{Wt. 294} & & \text{Wt. 343} & & \text{Wt. 196} \end{array}$$

(5) Conversion of calcium carbonate to calcium sulphate, carbon dioxide, and water:

$$\begin{array}{ccccccccc} \text{1 molecule} & & \text{1 molecule} & & \text{1 molecule} & & \text{1 molecule} & & \text{1 molecule} \\ CaCO_3 & + & H_2SO_4 & = & CaSO_4 & + & CO_2 & + & H_2O \\ \text{Wt. 100} & & \text{Wt. 98} & & \text{Wt. 136} & & \text{Wt. 44} & & \text{Wt. 18} \end{array}$$

If 196 parts by weight of sulphuric acid are required to convert 310 parts of tricalcium phosphate into monocalcium or soluble phosphate, then 0.632 part of acid will be required for every 1 part of tricalcium phosphate. If we use ordinary "chamber acid" of 50° B. strength which contains, according to the table on page 5, 62.18 per cent of sulphuric acid, 1.016 parts will be necessary for every 1 part of tricalcium phosphate.

In Table III, modified from one prepared by Wyatt,[1] is given the quantity of sulphuric acid of various strengths necessary to bring about the reactions outlined above.

TABLE III.—*Weight of "chamber acid" of various strengths required to convert one pound of each of the ingredients of phosphate rock into soluble compounds.*

Material acidulated—Ingredient.	Quantity and strength of acid required.							
	48° B.	49° B.	50° B.	51° B.	52° B.	53° B.	54° B.	55° B.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Tricalcium phosphate ($Ca_3(PO_4)_2$)	1.060	1.040	1.016	0.992	0.970	0.948	0.927	0.907
Calcium fluoride (CaF_2)	2.117	2.067	2.019	1.972	1.928	1.885	1.843	1.803
Iron phosphate ($FePO_4$)	1.640	1.601	1.564	1.528	1.494	1.460	1.428	1.397
Aluminum phosphate ($AlPO_4$)	2.023	1.975	1.929	1.885	1.842	1.801	1.761	1.723
Calcium carbonate (($CaCO_3$))	1.652	1.613	1.576	1.539	1.504	1.471	1.438	1.407

Table IV gives the quantities of sulphuric acid of various strengths required for every 100 pounds of the phosphate rock.

TABLE IV.—*Quantities of "chamber acid" required (theoretically) to convert 100 pounds of Florida hard rock phosphate into acid phosphate.*

Components of rock.	Per cent.	Strength and quantities of acid required for 100 pounds of rock.			
		48° B.	50° B.	52° B.	54° B.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Tricalcium phosphate ($Ca_3(PO_4)_2$)	80.0	84.8	81.3	77.6	74.1
Calcium fluoride, (CaF_2)	4.5	9.5	9.1	8.7	8.3
Iron phosphate, ($FePO_4$)					
Aluminum phosphate, ($AlPO_4$)	6.0	12.1	11.6	11.1	10.6
Calcium carbonate, ($CaCO_3$)	3.5	5.8	5.5	5.3	5.0
Silica, (SiO_2)	5.5				
Moisture, (H_2O)	.5				
Total		112.2	107.5	102.7	98.0

[1] Phosphates of America.

It has been found, however, that the quantity of sulphuric acid theoretically required to convert phosphate rock into acid phosphate does not always produce the best results. The physical condition of the acid phosphate is just as important as its chemical composition, and sometimes the proper mechanical condition can not be obtained except by sacrificing some of the water-soluble phosphate. In factory practice it is often well, therefore, to add a little less sulphuric acid than is necessary to satisfy the equations outlined above.

The strength of sulphuric acid used is another detail of great importance in the production of acid phosphate. The quantity of strong acid sufficient to bring about the desired chemical reactions is of such small bulk and has such a viscosity that it is difficult to obtain an intimate mixture with the ground phosphate; moreover, the calcium sulphate produced, being much less soluble in strong than in weak sulphuric acid,[1] forms a relatively insoluble coating over the phosphate, preventing further action by the acid.

On the other hand, if very dilute acid is employed, the amount required to bring about the necessary chemical reactions is so great and so much water is contained therein that it is almost impossible to obtain a product in good mechanical condition. The strength of acid with which the best results are ordinarily obtained ranges from 50° to 55° B., though phosphates very high in iron and aluminum compounds sometimes yield better to slightly stronger acid.

There is considerable difference of opinion concerning the temperature at which sulphuric acid should be added to phosphate rock. Some manufacturers, however, give little heed to this important point, mixing their acid and rock in the same proportions winter and summer at whatever temperature the air happens to be. Others believe in heating the acid to 50° to 55° C. before using, while many others claim it is bad practice to use acid at a temperature below 25° or above 30° C.

It is obvious that this matter should not be disregarded entirely, for in mixing acid and rock either very low or excessively high temperature may seriously affect the product. No definite rule, however, can be prescribed, for here again the composition of the phosphate used is the controlling factor.

Phosphates containing large quantities of carbonates heat up rapidly when mixed with sulphuric acid. If the mixture becomes very hot violent frothing occurs and the mass is apt to overflow from the pan. Rocks of this type should not be treated with hot acid. When dealing with phosphates high in compounds of iron and aluminum, however, it often saves time to use acid heated to a temperature of 50° to 55° C. The reactions then begin promptly in the pan and

[1] Bul. 33, Bureau of Soils, U. S. Dept. of Agr., pp. 41–42 (1906).

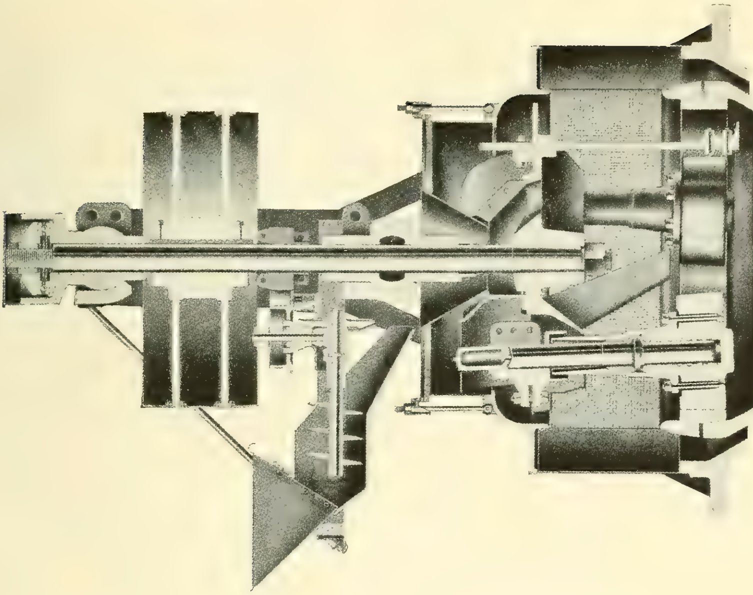

FIG. 2.—INTERIOR CONSTRUCTION OF RING ROLL MILL.

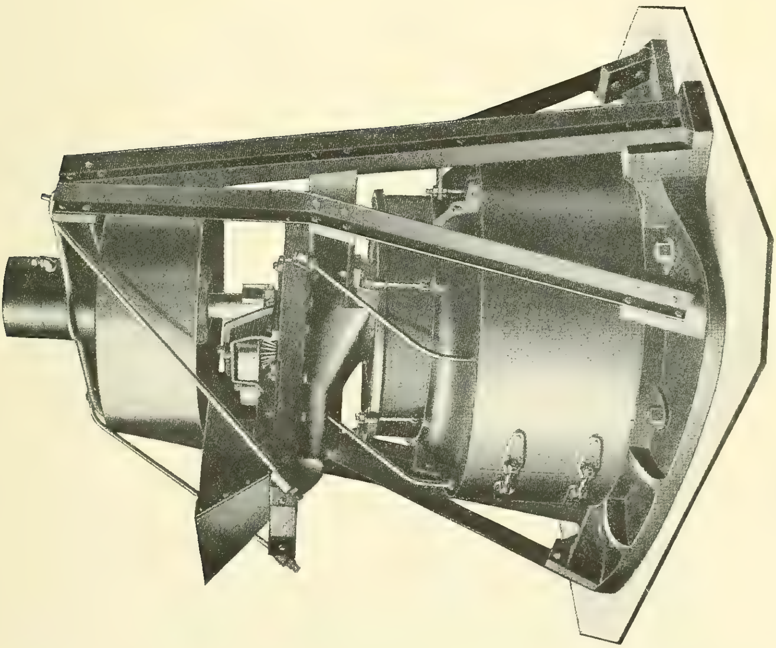

FIG. 1.—RING ROLL MILL CLOSED—READY FOR OPERATION.

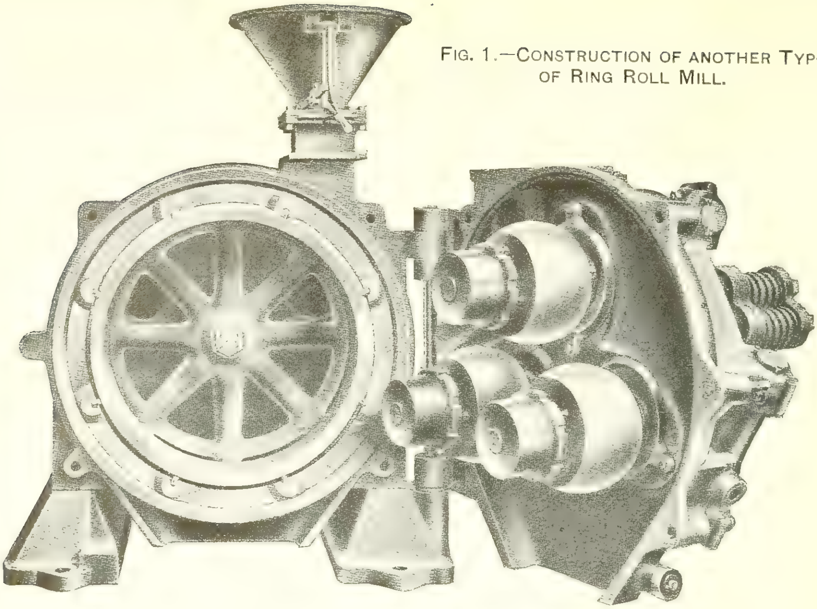

FIG. 1.—CONSTRUCTION OF ANOTHER TYPE OF RING ROLL MILL.

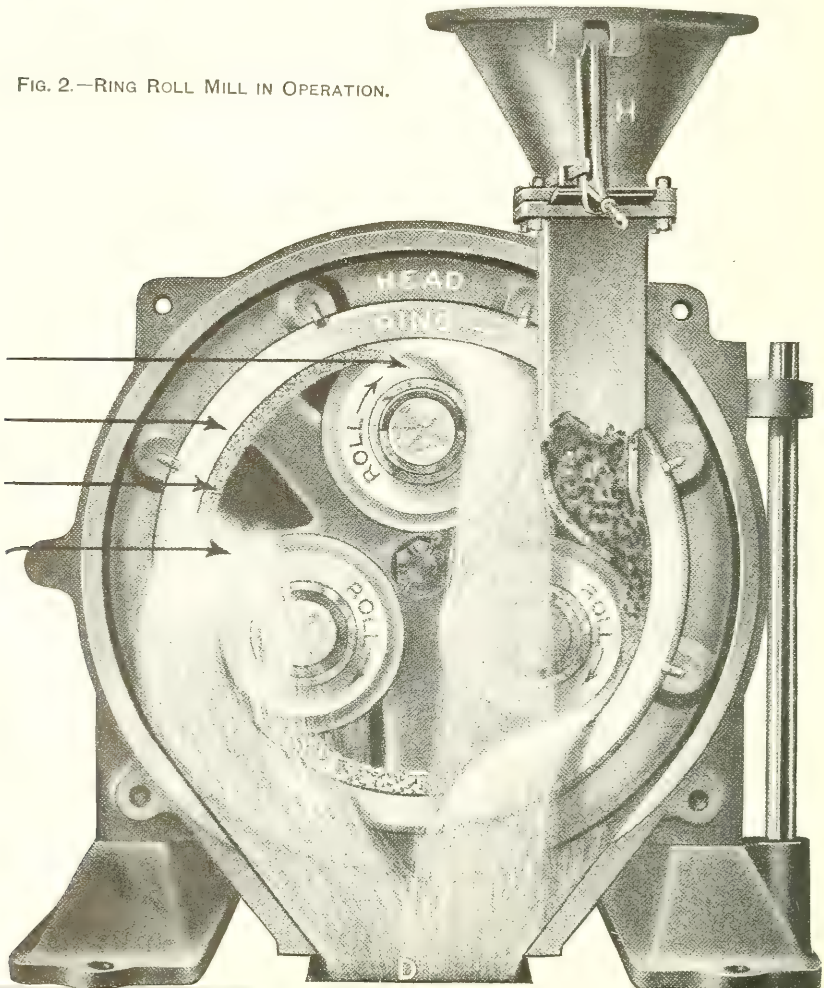

FIG. 2.—RING ROLL MILL IN OPERATION.

the mixture can be dumped without fear of its cooling before the final chemical changes take place.

MIXING THE ACID AND ROCK.

When the manufacture of acid phosphate was first suggested by Liebig, and for many years afterwards, the mixing process was all done by hand. Certain proportions of acid and rock were dumped into shallow, open pits or troughs and worked with hoes in a manner similar to that in which mortar is mixed. The material was then allowed to stand in the pit until the chemical reactions were complete and the superphosphate dry enough to be dug out. The modern factory process has almost entirely displaced this pioneer method of making acid phosphate. Machines are now employed which are capable of mixing efficiently, in two to five minutes, quantities of rock and acid weighing from 1 to 2 tons.

There are several types of mixers or acidulators used in this country, and the following general description applies to almost all of those ordinarily employed: A cast-iron revolving pan from 4 to 8 feet in diameter and from 1 to 2 feet deep is driven by pinions. The pan is equipped with either one or two agitators or stirring devices which consist of heavy iron spiders having four arms fitted with steel plows. These stirrers are driven by bevel gears. In the center of the pan is the discharge hole, which is closed by a valve operated by a lever. This same lever also controls a scraper which is lowered into the pan as the plug is raised. Figures 1 and 2, Plate IV, show the construction of an efficient acidulator.

The weighed charges of acid and rock are run into the revolving acidulator at the same time and stirred for at least two minutes or until an intimate mixture is obtained. The lever which controls the scraper and discharge valve is then lowered and the material ejected into the "den" directly below or into a car which hauls it to the storage shed and dumps it on a pile.

Both the "den" and "open dump" systems of making acid phosphate are employed in this country. Each has points to recommend it and each has certain objectionable features.

THE DEN SYSTEM.

This system was devised in order that the reactions between the phosphate rock and sulphuric acid might take place rapidly and yield a dry, pulverulent product of high availability (so called) in the least possible time.

As fast as the charges of acid and rock are mixed they are dropped into a closed, brick-lined chamber (den), which is filled to within a short distance of its top. Here the chemical reactions taking place raise the temperature to 120° to 250° C. Carbon dioxide, steam, and gaseous compounds of fluorine work their way out of the mass and escape through the flue at the top of the chamber, leaving the acid phosphate in a dry, porous condition.

After standing in the den for about 24 hours the reactions are practically complete and the material is ready to be removed. The heavy wooden doors at opposite sides of the den are then opened and the acid phosphate is removed. Frequently the floors of the den are so constructed that they can be opened and the acid phosphate discharged into a hopper or upon an acid-proof belt beneath, whence it is taken up by elevators and dumped on the storage pile. The emptying of the den is not only a disagreeable operation, but is attended with considerable danger. The temperature of the acid phosphate contained therein, even after standing from 24 to 36 hours, is still very high (from 130° to 150° C.), and the fumes given off by this hot material are quite poisonous. Great care must be exercised in digging out the phosphate to prevent large masses of the loose material from falling upon the laborers.

In order to do away with these dangers efforts have been made to empty the dens mechanically. A number of processes have been devised [1] in most of which the excavator or cutter is introduced into the chamber after the acid phosphate is cured. Special forms of chambers are required in some of the processes, while in others the excavating device is adaptable to almost any form of den after the latter has undergone some slight alterations. The more general scheme of emptying the dens mechanically is as follows:

A device consisting of an endless chain, which either rotates on a shaft or can be moved laterally in the den, is fitted with knives or teeth which cut or break up the acid phosphate and at the same time convey it to a chute. This device is either introduced horizontally at the top of the den or vertically at the side. In the former case the cutter is so arranged that it is mechanically lowered or sinks automatically after completing the circuit of the chamber. If the cutter is introduced vertically at one end of the chamber it cuts away the pile of acid phosphate from the side. It is claimed that the latter method is less likely to cause the material to pack. The removal of acid phosphate mechanically seems to be ordinarily a rather slow process, since the cutters or scrapers, if run at any great speed, cause the material to become heated and gummy. One process of emptying the dens more rapidly consists of a combined cutter and fan. The latter helps keep the material cool while excavation is going on. Another method of emptying the den consists of having the floors mounted on rollers so that one side of the chamber may be swung open and the whole mass of acid phosphate wheeled

[1] U. S. Patents 892,593, 899,042, 940,583, 949,055, 956,792, 1,013,334, 1,037,464, 1,033,854, 1,070,296.

out and broken up where there is a good circulation of air. Mechanical excavators have not been successfully worked in the factories of this country, however, and the old-style chamber or den is employed almost entirely.

The den system is the only one which can be successfully employed where it is necessary to absorb the fumes given off in the manufacture of acid phosphate. Each den is equipped with a flue near the top, which allows the gases and vapors from the freshly made acid phosphate to escape or be drawn off by means of a fan. The flue leads into a washer or scrubber, which consists either of a wooden tower in which jets of water are constantly spraying or of a number of compartments through which the gases are made to circulate while they are continually sprayed with water. Under such conditions the gaseous compound silicon tetrafluoride is decomposed with precipitation of silica and formation of hydrofluosilicic acid, as shown in the equation on page 8. The hydrofluosilicic acid, together with any hydrofluoric acid which may have escaped from the mass of acid phosphate, is absorbed by the water. The acid solution thus produced is used to some extent in the manufacture of fluosilicates of the alkalies which are used in the production of enamel.

Both the initial cost and running expenses of the "den" system are greater than those of the "open-dump" method, but a high-grade product in excellent mechanical condition can be obtained in a short time by the former method without allowing the objectionable fumes to escape into the atmosphere. Most factories are equipped with at least two dens (sometimes four) built close together, with the acidulator or mixer placed on the dividing wall above them. In this way work can be carried on with little interruption, for while one den is being emptied the other may be filled. The capacity of the dens varies from 50 to 300 tons, depending on the size of the mixing plant.

THE OPEN-DUMP SYSTEM.

The "open-dump" method is largely used in the South Atlantic States. The mixture of acid and rock is discharged into an automatic dump car and carried to the storage shed, where it is dumped on an open pile. In order that the chemical reactions may get a fair start before the mixture spreads out in thin layers, it is allowed to heat up and thicken somewhat in the mixing pan; frequently it is permitted to remain in the dump car until it has nearly set. Many operators, however, claim to obtain good results by dumping the material almost immediately. Sometimes, in order to prevent the acid phosphate from spreading, a partly open bin is employed. The material after standing in this bin for 8 or 10 days is taken up by elevators and dumped on a storage pile.

The acid phosphate made by the "open-dump" method naturally takes much longer to arrive at its maximum availability and optimum mechanical condition. It is usually kept for at least one month before shipping, but adverse weather conditions may delay shipment considerably longer and even seriously affect the quality of the final product. The production of acid phosphate by the "open-dump" method is impracticable in the vicinity of towns or in a rich farming country unless phosphate rock very low in fluorine compounds is used, for the fumes given off during the process are not only so obnoxious as to constitute a nuisance, but are quite injurious to both animal and vegetable life. At points where these fumes do no harm, however, and where the climate is not too cold, an excellent product is obtained by this method at less cost and with less danger than by the "den" system.

THE DRYING OF ACID PHOSPHATE.

Acid phosphate which is carefully made, especially that produced by the "den" system, seldom requires any subsequent drying. It is customary abroad, however, to dry superphosphates artificially, particularly when they contain an excess of phosphoric acid or are in a poor mechanical condition due to improper mixing. There are two general methods employed in drying acid phosphate. The first consists of the application of artificial heat and the second of adding some material to take up or combine with the water or free phosphoric acid present.

In Europe a number of machines for artificially drying acid phosphate have been patented. Among the most efficient of these are the dryers of Lutjens and of Moller and Pfeiffer.[1] In both of these machines the disintegrated acid phosphate is submitted to the action of a current of hot air under pressure. No direct heat can be used in drying acid phosphate because of the tendency of the material to revert at high temperatures.

The second method of drying acid phosphate is often practiced in this country when the material is too sticky or wet (due to faulty manipulation) to be uniformly spread on the field or mixed with other fertilizer ingredients. Such a condition when due to an excess of phosphoric acid can be frequently remedied by mixing the sticky mass with small percentages of phosphate rock or limestone. If the condition is due to the presence of a large proportion of iron and aluminum, the addition of finely ground peat or calcined gypsum will dry the material. In expelling the water from acid phosphate by artificial heating the value of the fuel consumed must be added to the cost of production, but no matter how the drying is done it entails additional handling, which is always expensive and should be avoided.

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[1] Fritsch, Manufacture of Chemical Manures, pp. 123–129 (1911).

STORING THE ACID PHOSPHATE.

In order that the acid phosphate produced may contain a maximum quantity of soluble phosphoric acid when ready for shipment, it is usually stored in well-ventilated buildings for at least two weeks. During this time the quantity of the so-called available phosphoric acid should steadily increase. This is especially true of properly mixed acid phosphate made by the "open dump" method where the heat is not sufficiently great to bring about rapid chemical reactions.

On the other hand, the storing of acid phosphate for protracted periods in large piles often seriously impairs its mechanical condition and sometimes its chemical composition. The pressure exerted on the material in the lower part of the heap, coupled with its contraction as the mass cools, tends to pack it. When the formation of gypsum is still in progress the superphosphate often becomes so closely cemented that it is difficult to break up. Again, improperly mixed acid phosphate or that high in compounds of iron and aluminum when closely packed is very apt to become gummy or to revert. Porter [1] states that in making acid phosphate by the "open dump" method the material should not be discharged on the pile until it is stiff enough to "set up."

The storing of acid phosphate in medium-sized piles, however, should cause no trouble, provided it is not allowed to stand too long and the climatic conditions are not unfavorable. Even when the material improves by storing it is hardly economical to keep it over a few months, as the interest on the money invested more than counterbalances the added value of the product due to the increase in available phosphoric acid.

In Table V, the figures of which are taken from Fritsch,[2] the changes taking place in stored acid phosphate made from three different samples of Tennessee phosphate (A, B, and C) are shown.

TABLE V.—*Changes taking place in acid phosphate made from Tennessee rock on storing from $2\frac{1}{2}$ to $4\frac{1}{2}$ months.*

Sample.	Composition.								
	Directly after mixing.			After storing for $2\frac{1}{2}$ months.			After storing for $4\frac{1}{2}$ months.		
	P_2O_5.	$Fe_2O_3+Al_2O_3$.		P_2O_5.	$Al_2O_3+Fe_2O_3$.		P_2O_5.	$Al_2O_3+Fe_2O_3$.	
	Insol.	Insol.	Sol.	Insol.	Insol.	Sol.	Insol.	Insol.	Sol.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	2.27	....	1.16	2.35	1.21	0.82	2.30	1.00	1.31
B	2.20	1.05	1.34	2.33	1.20	1.05	2.23	1.12	1.30
C	1.98	1.01	1.57	2.32	1.17	1.31	2.48	1.12	1.38

[1] Jour. Ind. Eng. Chem., 3, 108 (1911).

[2] Manufacture of Chemical Manures, p. 137 (1911).

It is not stated whether the acid phosphate was made by the "open-dump" or "den" method, but an inspection of the table will show that little change has taken place in the material after keeping several months. In Table VI are given the analyses of two piles of acid phosphate sampled after standing certain definite periods of time. The acid phosphate in both cases was made by the "open-dump" system.

TABLE VI.—*Analyses of acid phosphate from two piles after standing for certain periods.*

Time of storage.	Available phosphoric acid.	Insoluble phosphoric acid.	Moisture.
No. 1:	*Per cent.*	*Per cent.*	*Per cent.*
3 days	15.70	2.05	12.80
10 days	16.63	1.02	12.70
6 months	16.93	.47	13.80
No. 2:			
13 hours	15.55	1.50	....
3 days	15.70	1.80	12.60
6 months	17.19	.18	13.94

Although the percentage of available phosphoric acid continued to increase after storing the material for several months, this increased availability was largely offset by a corresponding rise in the moisture content of the product.

DISINTEGRATING THE ACID PHOSPHATE.

Before acid phosphate can be bagged and shipped it must be broken up and put through coarse sieves. In the case of superphosphate which has been carefully made it often suffices to throw the material by means of shovels upon inclined screens, the force of the impact being great enough to disintegrate the lumps. When dealing with acid phosphate, however, which has been improperly made or stored for a long time, it is often necessary to use a machine for breaking up the material. The ordinary crushing devices do not answer for this purpose, owing to the tendency of the acid phosphate to pack or become sticky when pressure is applied, so disintegrators of a special type must be employed.

In a machine like that shown in Plate V, figures 1 and 2, complete pulverization is brought about by submitting the material to innumerable shocks, but in such manner that no opportunity is given the acid phosphate to pack or gum together.

The disintegrator consists of a number of concentric cages made up of steel bars, all of which are inclosed in a casing. The cages are usually four in number, the first and third attached to a shaft which revolves in one direction and the second and fourth attached to another shaft having the same axis but revolving in the opposite direction. The casing can be readily opened and the cages slid apart and cleaned, as shown in Plate V, figure 2.

The acid phosphate is fed through a hopper into the inner or smallest revolving cage and is thrown by centrifugal force against the bars and into the second cage, which is revolving in the opposite direction, From the second it is thrown into the third and then into the fourth, finally being discharged from the machine thoroughly disintegrated by the numerous impacts it has received. Two scrapers fitted to the outside cage prevent the material from adhering to the casing and clogging the machine.

After disintegration the acid phosphate is ready to be bagged or mixed with other ingredients to make a complete fertilizer.

COST OF PRODUCTION.

The cost of producing acid phosphate depends on a number of factors, which vary widely. These are the size, location, and equipment of the plant and the cost of the sulphuric acid employed in the process.

The use of rock mills which grind the largest quantity of rock with the least expenditure of time and power and the employment of mixers having a capacity of 2 tons instead of 1 ton tend to reduce the cost of acid phosphate per ton. Plants located at seaports, where the cost of manufacturing sulphuric acid is less and the price of Florida rock usually lower, can often produce acid phosphate cheaper than those located at inland points. On the other hand, factories located at inland points which are within easy access of the phosphate fields can obtain their phosphate rock cheaper than those more distant from the source of supply. Again, those plants which have their own acid factories can manufacture sulphuric acid cheaper than it can be bought by companies which do not make their own acid.

The initial cost of producing acid phosphate by the den system is greater than by the open-dump method, but since the material can be shipped much sooner when made by the former method, the greater cost is compensated somewhat by the more active capital.

At inland points, such as Atlanta, Augusta, and Birmingham, the cost of producing acid phosphate (16 per cent citrate soluble), exclusive of office expenses, varies from $6.75 to $8 per ton. At seaports, such as Charleston, Savannah, Baltimore, and Norfolk, the cost ranges from $6.20 to $7.50 per ton. In Table VII is given the cost of producing acid phosphate at a plant running under good conditions located at a seaport and using Florida phosphates.

TABLE VII.—*Average cost per ton (2,000 pounds) of acid phosphate manufactured in a den-system plant located at seaport and running at full capacity of 500 tons per week.*

Phosphate rock (1,133 pounds), at $5.09 per ton	$2.576
Sulphuric acid (1,080 pounds), at $4.75 per ton	2.565
Direct labor	.264
Five-eighths superintendent's salary	.091
Power, oil, and waste	.232
Insurance on $60,000, at 1.55 per cent	.035
Taxes on $75,000, at 1.25 per cent	.036
Depreciation on $60,000, at 10 per cent	.231
Interest on $75,000, at 6 per cent	.173
Total cost per ton	6.203

The figures given in Table VII were compiled from data obtained through personal inspection of the principal fertilizer factories of the South and East. The costs do not include overhead charges, which vary greatly according to the size and number of the plants run by a company.

DISPOSAL OF PRODUCT.

Acid phosphate is sold on the basis of its so-called available phosphoric-acid content, and is worth f. o. b. the factory from 40 to 56 cents per unit,[1] depending on the location of the plant and grade of the product.

The availability of phosphoric acid is determined by its solubility in a solution of ammonium citrate. There seems to be no scientific basis for the assumption that the amount of phosphoric acid thus dissolved is equivalent to the quantity which is readily available to crops. It is, however, a convention accepted by the fertilizer trade as well as by many agronomists and agricultural chemists.

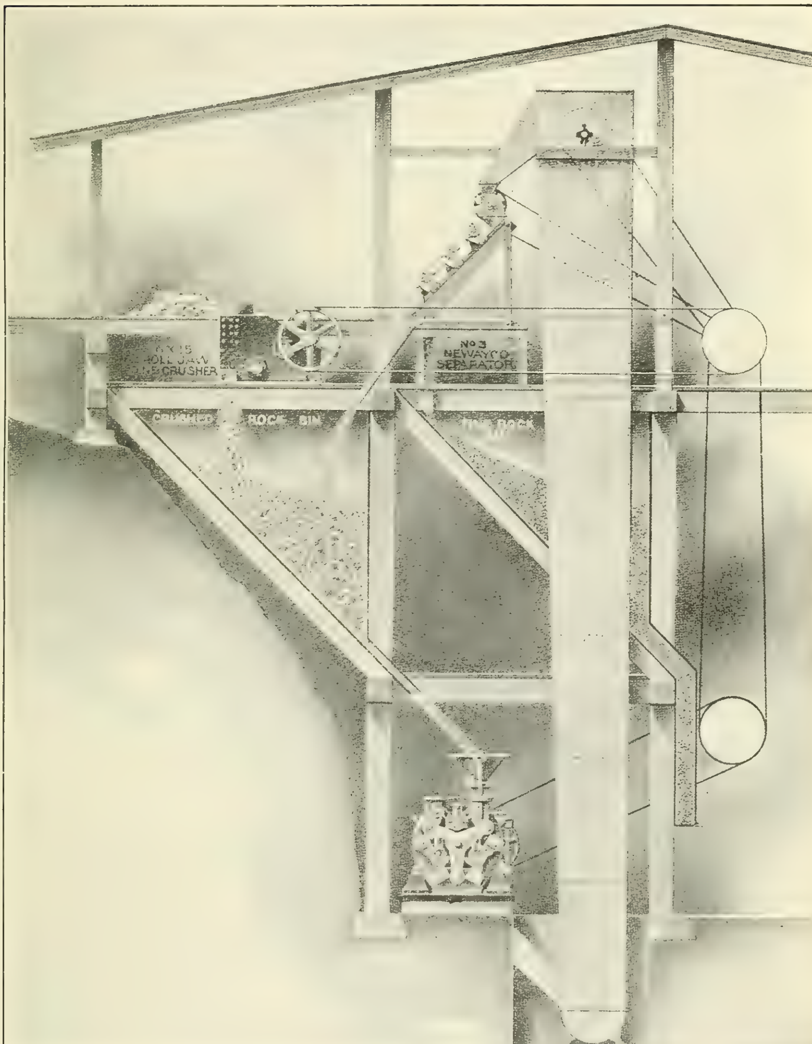
The phosphates of South Carolina (27 per cent P_2O_5) and those of northern Africa (26 to 30 per cent P_2O_5) yield as a rule acid phosphate containing 14 per cent available phosphoric acid.

Florida land-pebble phosphate gives an acid phosphate containing 16 per cent of available phosphoric acid, and the highest grade rock from Florida, Tennessee, and certain islands in the Pacific Ocean (containing from 35 to 38 per cent P_2O_5) yield a product containing from 18 to 21 per cent of available phosphoric acid.

Acid phosphate is usually put up in 200-pound sacks and shipped in closed box cars. The sacks are treated with a solution of silicate of soda, paraffin, or some other substance to prevent the acid phosphate from acting upon them.

The latest official figures on the output of acid phosphate are those for 1909, which show a total production of 3,062,834 tons. It is needless to say that the production has increased enormously since these figures were compiled.

[1] The unit is 1 per cent of a ton, or 20 pounds. One ton of 16 per cent acid phosphate contains 320 pounds P_2O_5.



CRUSHING, GRINDING, AND SCREENING PLANT.

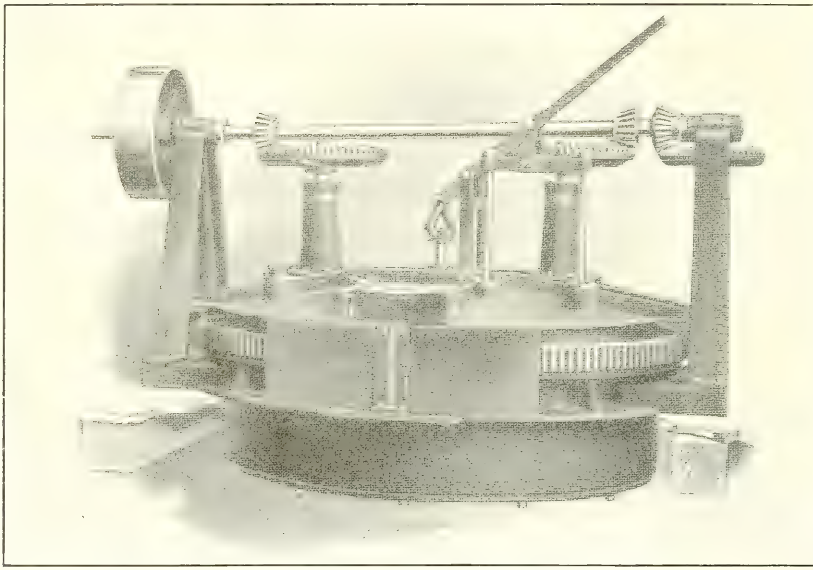


FIG. 1.—FAN FOR MIXING ACID PHOSPHATE.

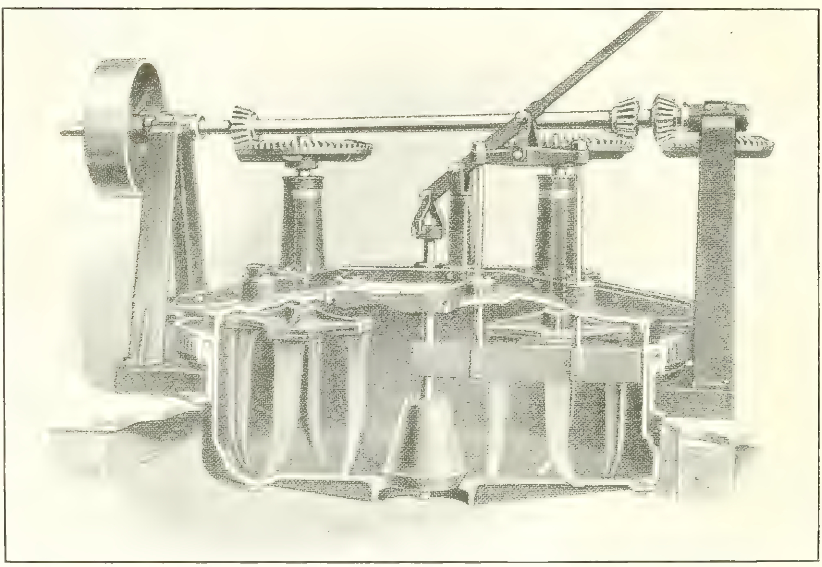


FIG. 2.—FRONT OF PAN BROKEN AWAY TO SHOW INTERNAL CONSTRUCTION.

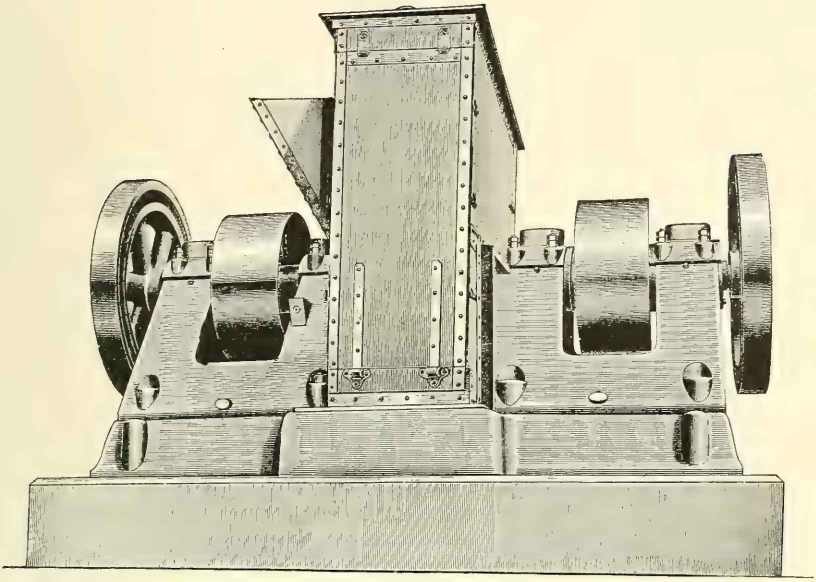


FIG. 1.—ACID PHOSPHATE DISINTEGRATOR CLOSED—READY FOR USE.

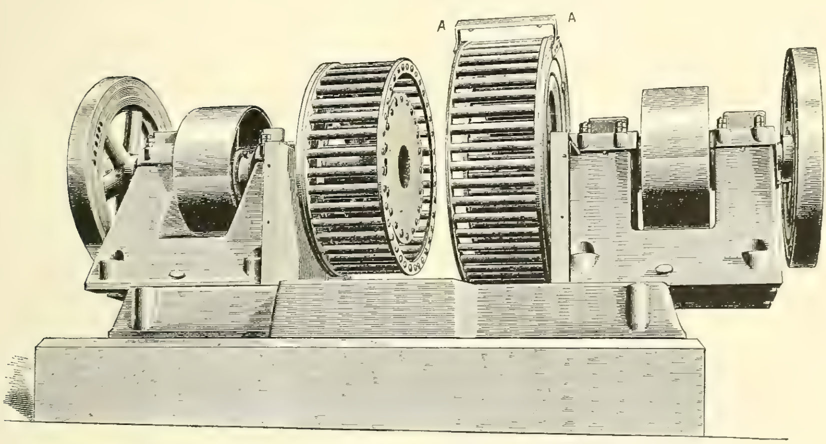


FIG. 2.—ACID PHOSPHATE DISINTEGRATOR OPEN TO SHOW CONSTRUCTION AND ACCESSIBILITY.

DOUBLE ACID PHOSPHATE.

The double acid phosphate now marketed contains from two to three times as much soluble phosphoric acid as ordinary superphosphate, and is therefore very valuable in the manufacture of concentrated fertilizers. Before the discovery of extensive deposits of high-grade phosphate rock, both in this country and abroad, the making of double superphosphate was widely practiced, since it afforded a ready means of utilizing low-grade phosphates. Now, however, most of the commercial rock is so high in phosphoric acid that it is unnecessary to resort to schemes for enriching the soluble product obtained therefrom, but in Germany, France, and several other foreign countries, as well as in the State of South Carolina, where a comparatively low grade of phosphate is mined, this process is still used with considerable success.

The two main chemical reactions involved in the manufacture of double acid phosphate are: First, sufficient dilute sulphuric acid is added to phosphate rock to convert the hypothetical tricalcium phosphate into phosphoric acid and gypsum; and second, the phosphoric acid thus obtained is used to convert the tricalcium phosphate of a fresh supply of rock into monocalcium phosphate. The reactions in their simplest form may be represented thus:

$$(1)\quad Ca_3(PO_4)_2 + 3H_2SO_4 = 2H_3PO_4 + 3CaSO_4$$

$$(2)\quad 4H_3PO_4 + Ca_3(PO_4)_2 = 3CaH_4(PO_4)_2$$

The process, however, is by no means as simple as it at first appears, for there are several distinct operations which not only require the watchfulness of a competent superintendent but the control of a skillful chemist.

The phosphate rock and dilute sulphuric acid (16° B.) are run into a vat simultaneously and stirred thoroughly for 15 or 20 minutes. It is inadvisable to use warm acid to decompose the rock or to stir for a protracted period, since under such conditions the compounds of iron and aluminum are dissolved only to be precipitated again later on, causing the reversion of a part of the phosphoric acid. The quantity of sulphuric acid required to bring about the desired reactions should be carefully ascertained from analyses of the raw material, since either an excess or an insufficient quantity will cause trouble in the subsequent operations.

The muddy solution is run into a tank from which it is pumped to a filter press where the sediment and gypsum is separated, the clear phosphoric-acid solution being run into evaporating pans. The residue in the filter press is then washed with water till the washings have a concentration of 0.25° B. or less. These washings are used to dilute the sulphuric acid employed in the process.

Before the phosphoric acid produced can be used for making double acid phosphate it must be concentrated. This is usually done by evaporating in iron pans lined with stone or some acid-resisting material. After concentrating to about 56° or 58° B., it is run into lead-lined tanks from which it is drawn or pumped as required. The mixing of this phosphoric acid with phosphate rock and all subsequent operations are practically the same as those employed in making ordinary acid phosphate, but the final product often has to be artificially dried since it contains but a small percentage of gypsum. Ordinary acid phosphate, as we have seen, is largely a mixture of soluble lime phosphate and gypsum, the latter having been formed from calcium sulphate by extracting the excess of water from the mass. Double acid phosphate, however, consists chiefly of soluble lime phosphate with but little calcium sulphate to act as a dehydrating agent, and therefore requires artificial heating to drive off the excess of water.

SUMMARY.

The general procedure followed in making acid phosphate involves numerous details of great economic importance which are not thoroughly understood.

The raw phosphatic materials which have been used in the acid-phosphate industry are bone, guano, apatite, and phosphate rock. Of these substances the last named has practically displaced the others as a source of phosphoric acid.

The process of making acid phosphate was devised in order to produce phosphoric acid in a soluble, or so-called "available," condition; this done by the action of sulphuric acid on tribasic phosphates whereby less basic and more soluble phosphates are produced.

A knowledge of the composition of the raw materials is of the greatest importance in the manufacture of acid phosphate, since not only the phosphate of lime but all the impurities contained in the rock are acted upon by sulphuric acid and influence the composition and physical condition of the finished product.

Much phosphate rock contains organic matter which consumes a certain amount of sulphuric acid, but owing to the various forms in which this material occurs it is almost impossible to determine except by actual trial the quantity of acid required to decompose it.

Silica is acted upon only indirectly by sulphuric acid.

Calcium fluoride, which is present in nearly all phosphate rock, is acted upon by sulphuric acid, resulting in the formation of gaseous hydrofluoric acid. This gas in turn acts upon silica and silicates, producing silicon tetrafluoride. The silicon tetrafluoride is decomposed by water, forming hydrofluosilicic acid and silica. The presence of fluorides is objectionable because of the obnoxious fumes evolved in treating with acid; otherwise this impurity is not objectionable.

Compounds of iron and aluminum are the most dreaded of the impurities occurring in phosphate rock. These elements when present in small quantities are very apt to cause a certain amount of reversion to take place, and when present in large quantities may render the product sticky and unfit for use. By careful handling, however, phosphates high in iron and aluminum compounds may be made to produce high-grade acid phosphate.

Carbonate of lime, which is present in nearly all phosphate rock, is a rather desirable impurity when the quantity is not excessive. The decomposition of this compound by sulphuric acid is attended with considerable heat which promotes chemical reaction between the more slowly acting substances in the mass; moreover, the calcium sulphate produced therefrom acts as a drier for the acid phosphate.

In the manufacture of acid phosphate the rock is first ground to pass a 60-mesh sieve, and then mixed with an equal weight (approximately) of "chamber acid." The quantity, strength, and temperature of acid used have an important influence on the quality of the product.

After thorough mixing in a cast-iron pan the material is discharged into a "den" just below the mixer or into a car which takes it to a shed and dumps it on a pile. When the "den" system is used the reactions take place rapidly and the product can be dug out in 24 to 36 hours, practically ready for shipment. The method of emptying the "dens" by hand, however, is attended with some risk owing to the poisonous nature of the fumes evolved from the freshly made acid phosphate and to the danger of large masses of the material falling on the laborers.

In the "open dump" system the acid phosphate requires a long time to reach its maximum availability, and unless it is properly made may never be fit for use.

The storing of acid phosphate in large piles for protracted periods sometimes causes reversion owing to the pressure on the material in the lower part of the pile; this pressure also tends to compact the material. The storing of well-made acid phosphate in medium-sized piles, however, should cause no ill effects.

Properly made acid phosphate should require no artificial drying, since the calcium sulphate formed in the process takes up the water to form gypsum. It is nearly always necessary, however, to disintegrate and screen the material before shipping. This is often done by simply throwing the product upon inclined screens, but sometimes disintegrating machines must be employed.

Acid phosphate is sold on the basis of its so-called available phosphoric acid, and has a value of 40 to 56 cents per unit. The marketed product contains from 14 to 21 per cent of phosphoric acid, depending on the raw material used in its manufacture.

Double acid phosphate is made by treating phosphate rock with sufficient diluted sulphuric acid to produce free phosphoric acid, and then using the phosphoric acid thus obtained to decompose a fresh batch of rock. The final product contains from two to three times as much phosphoric acid as ordinary acid phosphate, and is very useful in the making of concentrated fertilizers.

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PROFESSIONAL PAPER.

TESTS OF WOOD PRESERVATIVES.

By HOWARD F. WEISS, *Director*, and C. H. TEESDALE, *In Charge of Wood Preservation, Forest Products Laboratory, Madison, Wis.*

INTRODUCTION.

A list of the various substances that have been used or suggested for preserving timber from decay would include a surprisingly large number of those known to industrial chemistry. By-products for which no use could be found have often taken their last stand as possible preservatives of wood. There have been sent to the Forest Products Laboratory for test the condensed fumes of smelters, the waste liquors of pulp plants, the refuse of tanneries, the skimmed milk of creameries, and miscellaneous assortments of compounds under trade names. Many of these have not been tested, because the claims made for them were manifestly impracticable. Those, however, which showed some promise or about which numerous inquiries were received were admitted to test.

The object of the tests, which were carried on at the Forest Products Laboratory maintained in cooperation with the University of Wisconsin, was to secure data on the practical value of these compounds and chemicals as wood preservatives. More than this, however, it was thought that such an investigation would show clearly

[1] The following members of the Forest Products Laboratory performed the experiments herein described: Ernest Bateman, chemist in forest products; C. J. Humphrey, pathologist, Bureau of Plant Industry; Ruth Fleming, scientific assistant, Bureau of Plant Industry; Robert E. Prince, assistant engineer in forest products.

Acknowledgment is also made to Ira H. Woolson, consulting engineer, the National Board of Fire Underwriters, for valuable assistance in the inflammability tests, and to the following cooperators, who furnished some of the preservatives used: United Gas Improvement Co., Philadelphia, Pa.; Bruno-Grosch & Co., New York City; Carbolineum Wood Preserving Co., Milwaukee, Wis.; C. A. Wood Preserver Co., St. Louis, Mo.; Marden, Orth & Hastings, Boston, Mass.; Logged-Off Land Utilization Co., Seattle, Wash.; Lake Superior Iron & Chemical Co., Detroit, Mich.; Spirittine Chemical Co., Wilmington, N. C.; Materials Preserving Co., Burlington, Vt.; Atlantic Turpentine & Refining Co., Savannah, Ga.; Indian Refining Co., New York City; Copper Oil Products Co., New York City; Balaklalla Consolidated Copper Co., Coram, Cal.; Franz Workman, Scotland (representing Messrs. Bruening & Marmetschke); John M. Long, Winston, Va.; Philadelphia Quartz Co., Chester, Pa.; Blagden, Waugh & Co., London, England.

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the deficiencies of present practice in wood preservation and pave the way for increasing its efficiency by suggesting lines for orginal research.

From 40 to 90 per cent, or an average of over 60 per cent of the total cost of treating wood, is chargeable to the preservative alone. In ordinary treatments with coal-tar creosote it is common practice to inject 5 to 10 pounds of the oil per cubic foot of wood, although toxicity tests indicate that about one-half of a pound will prevent fungous growth; in other words, exclusive of subsequent changes, from 10 to 20 times as much creosote is used per volume of wood as is theoretically required. The possibility of safely reducing this amount, and consequently the cost of treatment, is one of the problems referred to. The tests described herein should therefore be considered simply as preliminary to the more difficult problems involved.

PROPERTIES INVESTIGATED.

The practical value of a preservative depends very largely upon the conditions under which it is used, and investigations to determine its value must necessarily be broad. The following points were considered in the tests:

(1) The important chemical and physical properties of the preservative.

(2) The effect of the preservative on the strength of the wood treated with it.

(3) The ability of the preservative to penetrate and diffuse through wood.

(4) The permanency of the preservative after its injection into wood. This involves a study of its volatility and leachability.

(5) The combustibility of wood treated with the preservatives.

(6) The toxic efficiency of the preservative in preventing the growth of wood-destroying fungi.

(7) The corrosive action of the preservative on steel.

(8) The effect of the preservative on paint applied to the wood subsequent to treatment.

No systematic tests were made on the effect of the preservative as an electrolyte or in contaminating drinking water, nor any tests which relate to a special or limited use.

METHODS OF TEST.

The various tests were conducted as follows:

Thoroughly air-seasoned eastern hemlock (*Tsuga canadensis* L.) was selected as the wood best suited for the experiment because of its low inherent resistance to attack by fungi, the comparative uniformity with which it can be treated, and its availability. Only perfectly clear, straight-grained, and uniform material, free from all mechanical and physical defects, was used. The pieces selected for test were 12 by 26 by $1\frac{1}{4}$ inches. These were cut and numbered as shown in *A*, Plate I. Some of the test specimens were left untreated; others after treatment were recut and renumbered as shown in *B*, Plate I.

The uses to which the specimens were put are given in the description of each test.

CHEMICAL AND PHYSICAL PROPERTIES OF THE PRESERVATIVES.

The chemical composition of each preservative, its specific gravity, viscosity, odor, flash, and burning points were tested by standard methods. In all distillations the apparatus described in Forest Service Circular 112 was used.

The specific gravity was determined chiefly by a hydrometer or by a Westphal balance. Viscosities were obtained by using the Engler orifice viscosimeter at various temperatures. The flash and burning points were determined by heating the preservative at a rate of 2° C. per minute in an open flash-point tester, passing a small flame over the surface every minute.

METHOD OF TREATING WITH PRESERVATIVE.

Pieces Nos. 4, 5, 6, 7, 12, 13, and 14–2 were treated with the various preservatives in an impregnation cylinder. Before treatment they were oven-dried at 100° C. in order to be sure that all specimens were as nearly as possible in a uniform moisture condition. They were then weighed and impregnated. The simplest procedure of treatment was followed. For example: After the wood was placed in the cylinder the preservative was admitted, displacing the air, until the cylinder was completely filled; a pressure of about 50 pounds per square inch was then applied until the desired absorption was obtained, when the cylinder was drained of excess preservative and the specimens removed and weighed within 24 hours. When necessary higher pressures than 50 pounds were used.

STRENGTH TESTS.

Pieces 1, 2, and 3, which were not treated, and 4, 5, and 6 (see *A*, Pl. I), which were treated with the preservative, were tested in bending to failure in an ordinary 30,000-pound testing machine, using a center load over a 12-inch span. Care was taken to have all specimens at approximately the same moisture content at the time of test (about 6 per cent) by allowing them to remain in the laboratory until they no longer absorbed moisture from the air. Specimens treated with oils usually contained a little less moisture than those untreated. After being broken, 3-inch specimens were cut from each end for fungus-pit tests (see *B*, Pl. I).

PENETRANCE OF THE PRESERVATIVE INTO WOOD.

The distribution of a preservative in the wood, a most important feature in any treatment, was studied as follows:

The central portions of sticks 4, 5, and 6, after the strength data had been obtained on them, were split, and the depth and character of the penetration recorded. This could usually be done visually, but with those preservatives which in aqueous solution were colorless, an aniline dye was used or the specimens were chemically analyzed.[1]

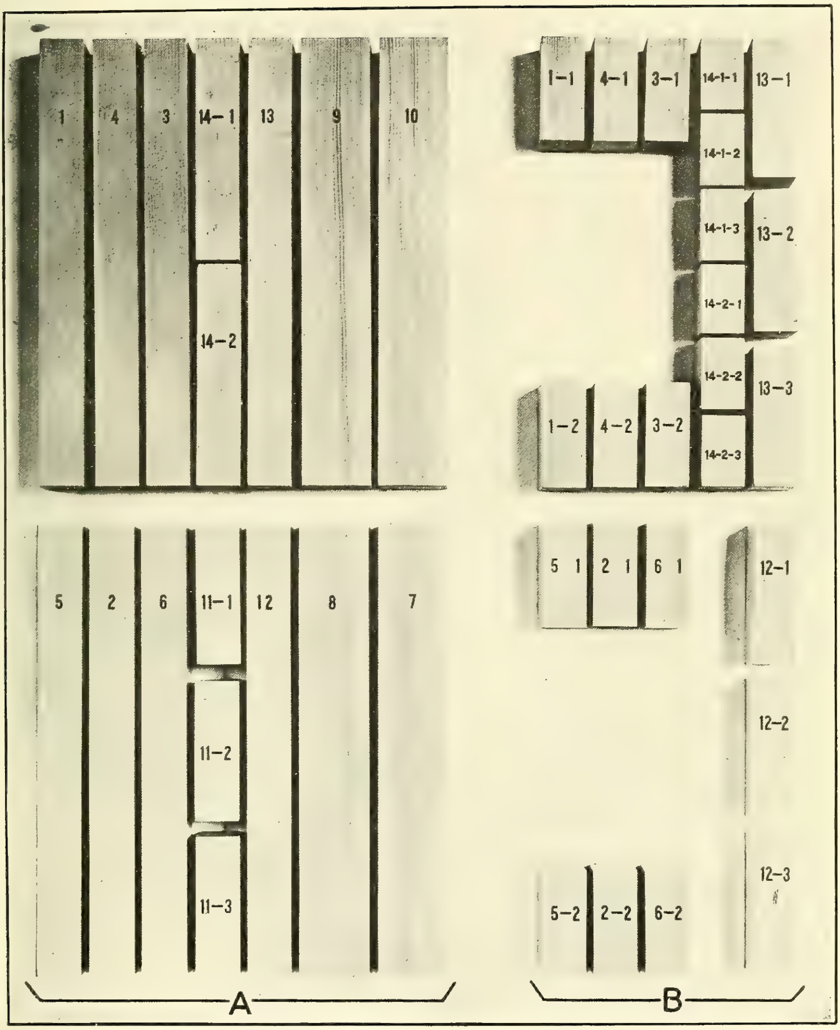
The results from these tests were used to supplement those secured from pieces 8, 9, and 10, which were tested in a specially-constructed penetrance apparatus (see Pl. II) operated in the following manner: A hole 1 inch in diameter was bored in the center of each stick (*A*) to a depth of three-fourths inch. The stick was then placed on the shelf (*B*) inside the apparatus for several hours, and after being weighed was clamped between two iron disks (*C* and *D*) so that the preservative could be forced into the hole from the tank (*E*) under a constant pressure and temperature. The stick was raised to a temperature of about 180° F. by the steam coils (*F*) before the preservative was admitted. The pressure was controlled by compressed air on the top of the preservative in tank (*E*). For oils, the length of the pressure period was 30 minutes, and for water-soluble salts 3 minutes, with the exception of sodium silicate, for which the time was prolonged to 30 minutes. The time it took to penetrate the wood longitudinally was noted.[2] At the end of these periods the specimen was sawed longitudinally and transversely through the center lines and the penetration radially, tangentially, and longitudinally was studied. (See Pl. III.)

VOLATILITY TESTS.

The volatility tests on oils were made to determine only the relative rates at which they left the treated wood. The plan of using matched pieces, as outlined in Plate I, was abandoned because the data obtained were inaccurate, the specimens reabsorbing moisture through the untreated end surfaces of the specimens cut after treatment. A new set of specimens was prepared from noble fir (each $1\frac{1}{4}$ by 2 by 6 inches) and treated for the volatility experiments. These were weighed separately and placed in the volatility apparatus (fig. 1), consisting of an air-tight metal box, 15 by 24 by 30 inches, through which a constant current of air, partially dehydrated by passing through calcium chloride towers, was drawn.

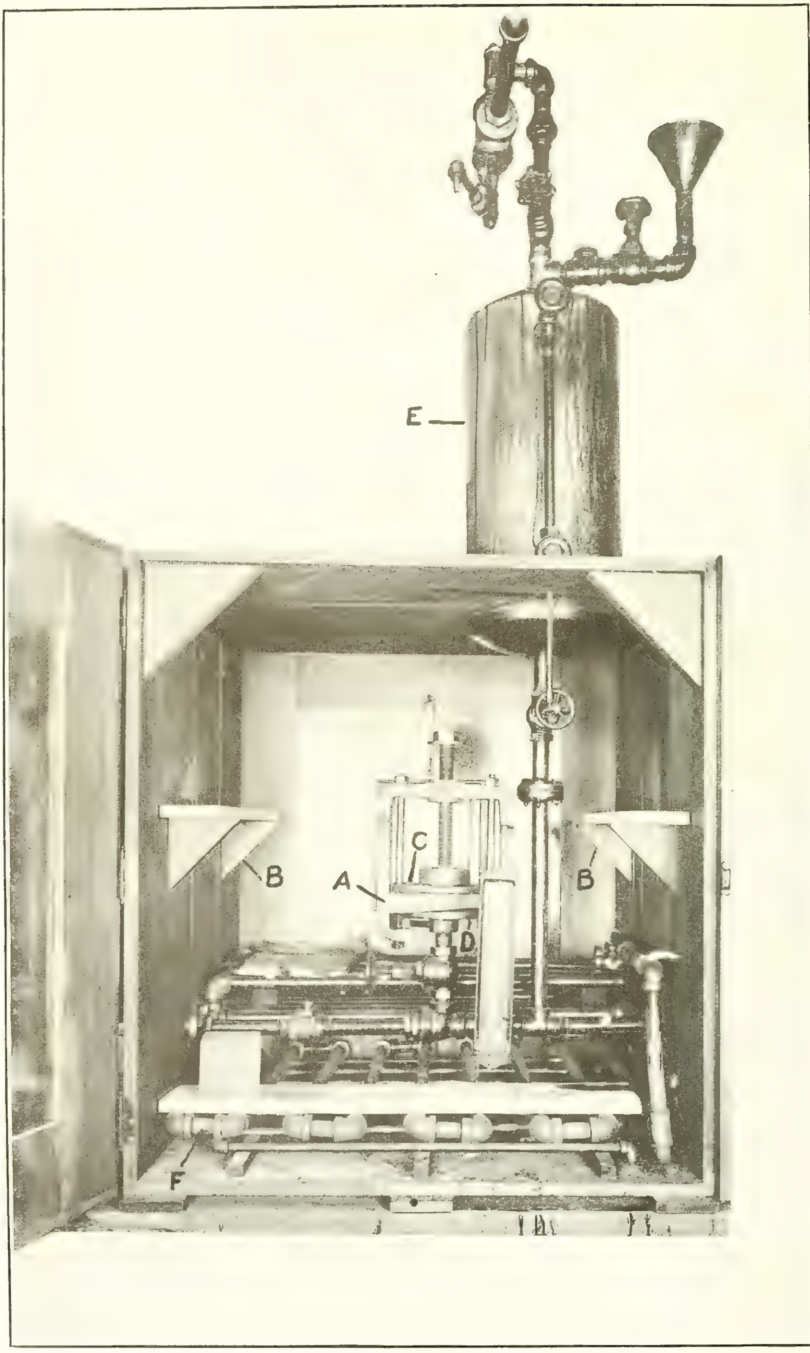
[1] It was found by repeated tests that water and the dye had a tendency to penetrate in some cases slightly farther than the preservative, although the difference was of no practical significance.

[2] A mirror placed in the back of the apparatus enabled the penetration in the rear end of the stick to be determined.

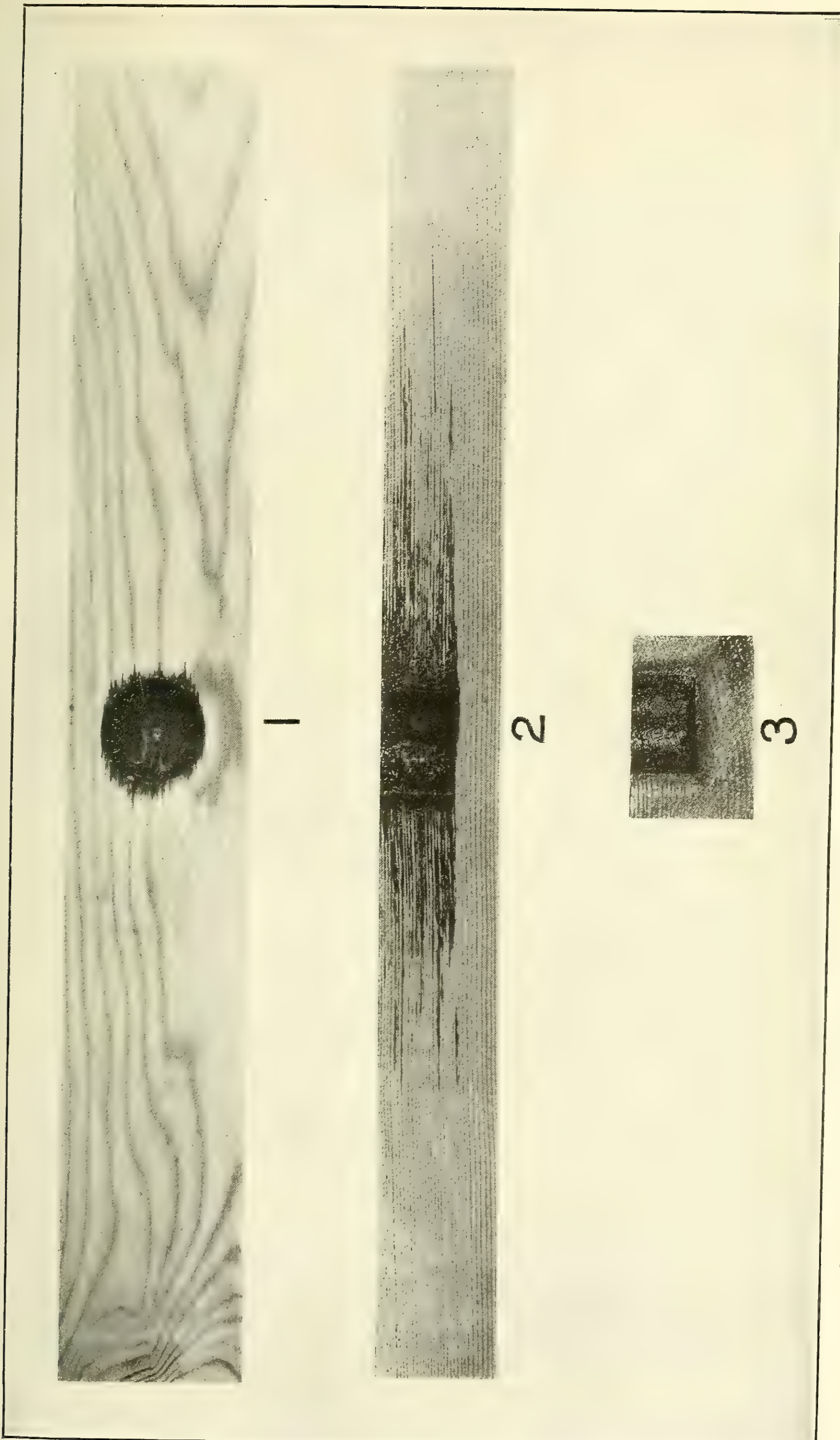


A.—Specimens cut thus before treatment. B.—Specimens cut thus after treatment.

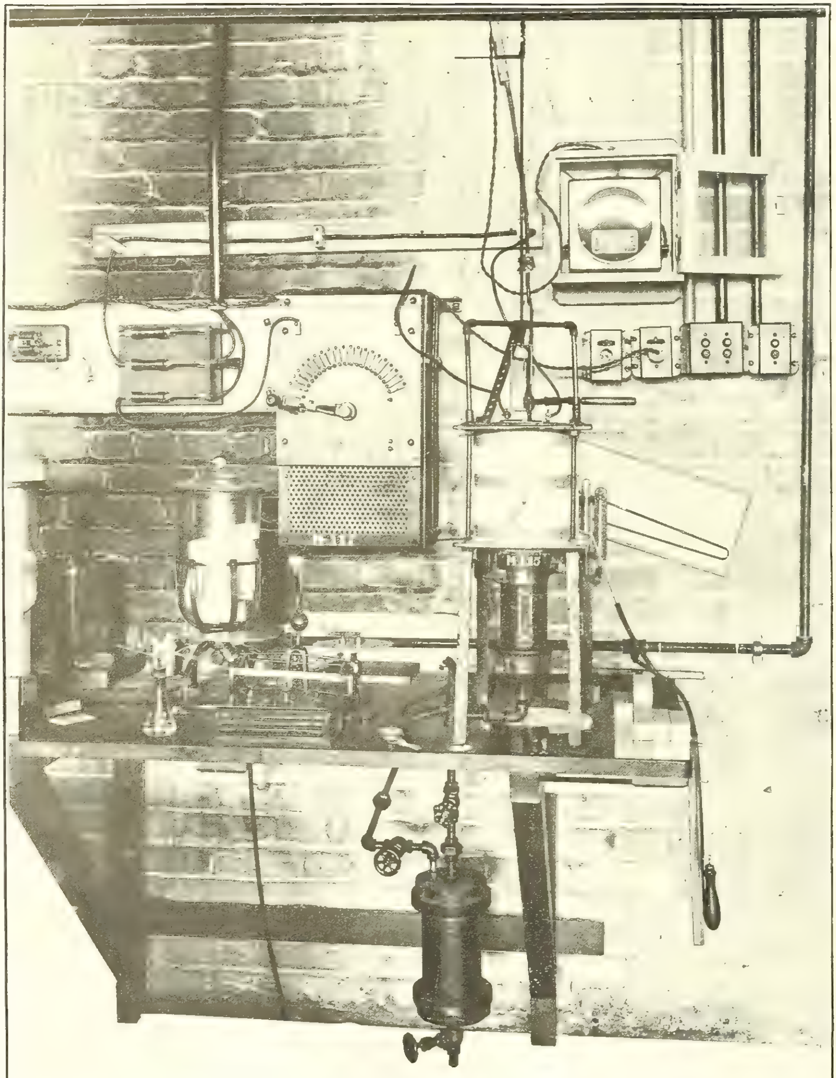
METHOD OF MATCHING AND CUTTING SPECIMENS.



APPARATUS FOR CONDUCTING TESTS ON PENETRANCE.



PENETRANCE SPECIMENS AFTER TREATMENT. 1. BEFORE BEING CUT. 2. CUT LONGITUDINALLY. 3. CUT TRANSVERSELY.



APPARATUS FOR DETERMINING RELATIVE INFLAMMABILITY.

The box was heated to 30° C. by electric lamps, the temperature being automatically controlled within 1° C. by a thermostat. The treated specimens were removed and weighed at weekly periods for 3 months, the loss in weight being taken as representing the amount of the preservative volatilized.

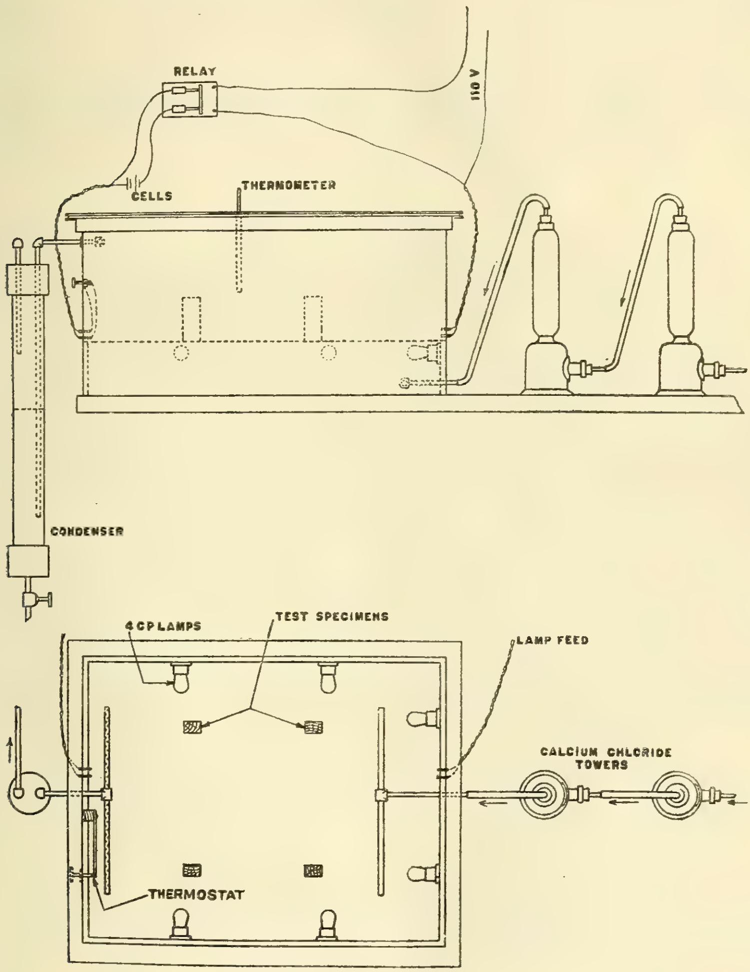


FIG. 1.—Apparatus for conducting tests on volatility.

LEACHING TESTS.

Tests were made on the water-soluble salts to determine the relative rates with which they leached from the treated wood. As soon as possible after treatment stick 12 was recut into three pieces, each $1\frac{1}{4}$ by $1\frac{1}{4}$ by 4 inches in size, and weighed separately to determine the amount of preservative it contained.

The test pieces were then submerged in a glass jar containing 300 c. c. of distilled water at room temperature. This water was changed at stated intervals and analyzed for the presence of preservative. The total time of leaching was 4 weeks. To check the amount of preservative remaining in the wood after the total submersion period the specimens were shredded and chemically analyzed. Owing to the large amount of preservative which adhered to the surface of the wood, and the absorption of some of it, it was extremely difficult to secure satisfactory results on leaching. For this reason no values are given. Recent experiments indicate that not only do the different salts leach at different rates, but also various concentrations of the same salt.

INFLAMMABILITY TESTS.

The crib and shaving tests frequently used in testing the combustibility of wood proved unsatisfactory, and a new form of apparatus was finally developed with which more comparable results were obtained. This apparatus (see Pl. IV) consists of a silica tube, wrapped with nichrome ribbon. An iron tube fitted with a mica sight was cemented below the silica tube.

The specimen of wood, after being lowered in the silica tube, was heated at a uniform rate by passing 24 amperes of electric current at 110 volts through the nichrome ribbon. Temperature readings were obtained from a thermocouple placed beside the specimen and reading direct from a Hoskins pyrometer indicator. A pilot light was used to ignite the gases distilled from the wood. Compressed air partially dehydrated by expansion was passed through the apparatus, its intensity being indicated by a sensitive liquid manometer. Three untreated test specimens cut from stick 11 (see Pl. I) were burned as a check against the three treated specimens cut from stick 13. When the preservative was a water-soluble salt, the test specimens were first air-dried and then oven-dried before ignition. When the preservative was an oil, one inflammability test was made within 24 hours after impregnation and another after three months' seasoning in the volatility apparatus, the latter being made on specimens cut from stick 12.[1]

TOXICITY TESTS.

Because of the importance of toxicity tests and the inherent objections to various established methods of testing, three independent methods were followed:

(1) Petri-dish method, in which the preservative is mixed with a culture medium and inoculated with fungi.

[1] Stick 12 was used for leaching tests in the treatments with water-soluble salts, and for inflammability tests after 3 months' seasoning in the volatility apparatus in the treatments with oils.

(2) The injection of the preservative into wood, with a subsequent exposure to pure cultures of wood-destroying fungi in sterilized jars. Specimens recut from stick 14, as indicated in *B*, Plate I, are being used for these tests.

(3) The injection of the preservative into wood with subsequent exposure to various fungi in a fungus pit. Specimens recut from sticks 1 to 6, inclusive, as indicated in *B*, Plate I, are being used for these tests.

At present tests by the petri-dish method are the only series that have advanced far enough to be reported upon.

PETRI-DISH TESTS.

In these tests the culture medium consisted of the extract of 1 pound of lean beef in 1,000 c. c. distilled water, to which is added 25 grams Löfflunds malt extract and 20 grams agar-agar.

The medium and preservatives were sterilized at 100° C. in separate sealed containers, then thoroughly mixed together and poured into petri dishes 100 mm. in diameter and 10 mm. deep. (See Pl. V.) After hardening, the agar-preservative mixture was inoculated at the center with the mycelium of a wood-destroying fungus (see Pl. V), and the cultures then placed in an incubator held at approximately 25° C. for from 4 to 6 weeks. The growth was observed usually at intervals of about a week. Plate V shows the appearance of these cultures of fungi in various stages of development. This test is considered by the Forest Service as merely tentative. While it is open to certain objections, such as the possible chemical combination of certain of the preservatives or their constituents with the media, it nevertheless offers considerable advantage in giving quick indications of the toxicity of a substance, in that way indicating the most promising preservatives for further work.

The results of tests to date on the fungi *Fomes annosus* (Fr.) Cke. and *Fomes pinicola* (Sw.) Fr. are summarized in Table 5.[1]

CORROSION TESTS.

To determine the corrosive action of the preservative on steel, so that possible deterioration in a treating cylinder might be ascertained, a strip of boiler flange steel of the quality specified by the American Society for Testing Materials, August 16, 1909, was submerged in the preservative and heated to a constant temperature of about 98° C. The preservative was changed every week for 4 weeks in the case of oils; with aqueous solutions, it was changed every day for 1 week. The difference in the weight of the steel before and after

[1] Concentrations in this table are based on the actual *weight* of preservative in 20 c. c. agar-preservative mixture.

submersion was taken to indicate its corrosion. All depositions on the surface of the metal were removed as nearly as possible with a rubber "policeman" each time the preservative was changed. At the end of the tests, where electrolytic deposition of metal had taken place, the deposited metal was removed by acid and its amount determined by an analysis of the acid solution. The weight of deposited metal thus determined was added to the loss of iron, and this total represented the total corrosion. The figures thus obtained were then calculated to ounces of steel corroded per square foot of surface exposed per week.

PAINT TESTS.

The treated wood was first air-seasoned for about 1 month to permit water and light oils to evaporate, and then coated with white paint (30 pounds of lead oxide to 1 gallon of linseed oil), noting the color change which subsequently took place. This test was made in order to determine the practicability of painting treated wood.

The results of the tests on wood treated with water-soluble salts were favorable, and the scope of the tests was therefore enlarged.

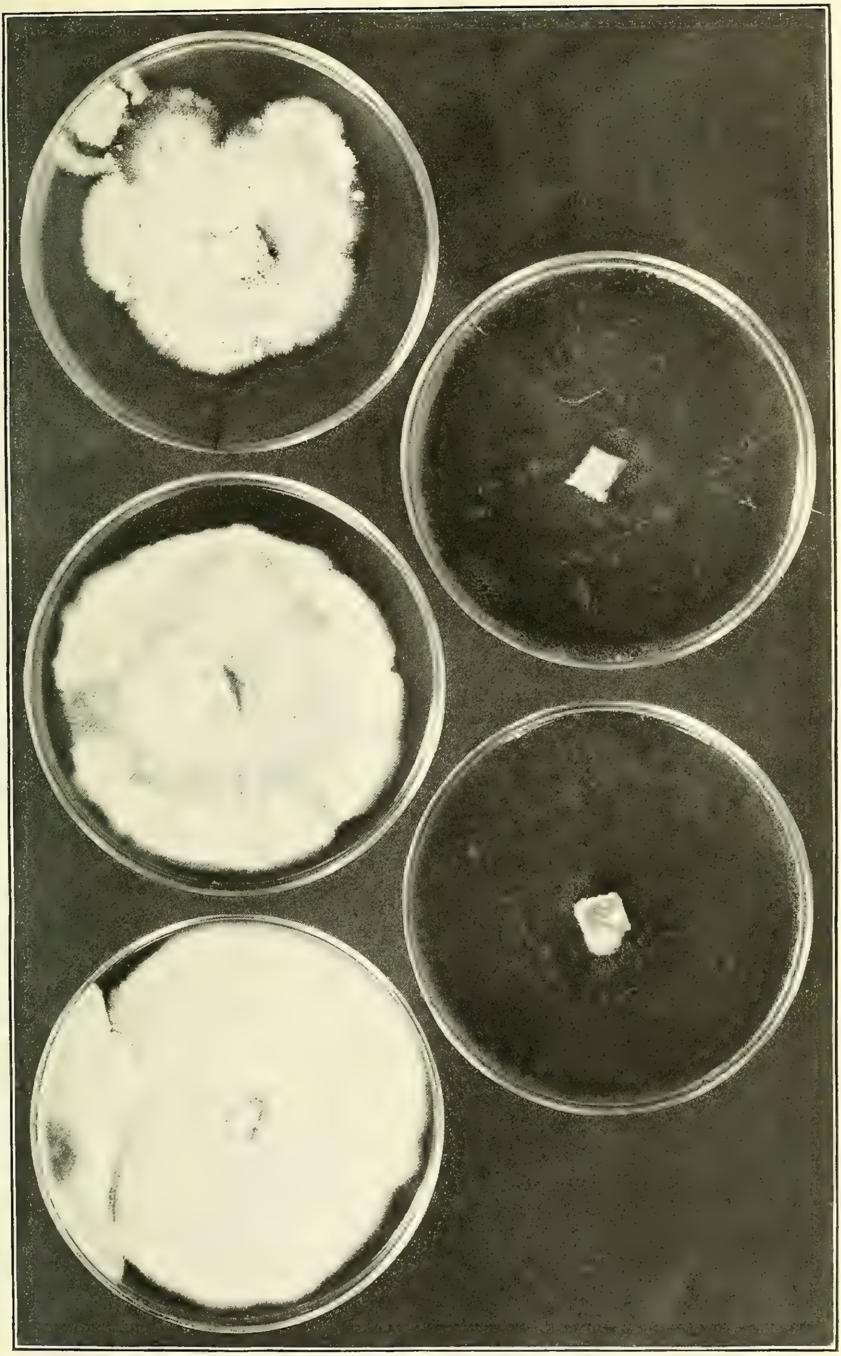
Specimens of noble fir, 1 by 4 by 12 inches, were treated with zinc chloride and sodium fluoride, and painted with white-lead paint. Untreated specimens were also painted for comparison. Four specimens were used in each set. One specimen from each series was placed in running water or in the moist atmosphere in the fungus pit, and two exposed to the weather.

These tests also indicated that wood treated with these salts could be successfully painted, and arrangements were then made with the National Paint Manufacturers' Association for a more extensive test.

White pine panels, 2 by 3 feet by 1 inch, were treated with zinc chloride, sodium fluoride, and ammonium phosphate. Six panels were treated with each preservative and six were used untreated. These were sent to the Institute of Industrial Research, Washington, D. C., where they were painted under the direction of Mr. Henry A. Gardner, representing the National Paint Manufacturers' Association. After painting, the panels were divided into three sets—one of which is exposed at Atlantic City, N. J., one at Washington, D. C., and the third at St. Louis, Mo., under the direction of Dr. Hermann von Schrenk.

RESULTS.

The results secured from the experiments may be changed by subsequent tests, since the field covered is new and errors in manipulation, not at present apparent, might exist. Every feasible precaution was taken, however, to avoid errors, and those known and uncontrollable are mentioned.



PETRI-DISH TESTS SHOWING RETARDATION OF GROWTH AS THE PER CENT OF TOXIC AGENT IS INCREASED.

PHYSICAL AND CHEMICAL PROPERTIES.

The results of the tests on physical and chemical properties are given in Table 1.

EFFECT OF THE PRESERVATIVE ON THE STRENGTH OF WOOD.

Table 2 gives the results of the tests on the effect of the preservative on the strength of wood.

As a greater accuracy than plus or minus 10 per cent could not be obtained in these tests, largely because of variables inherent in wood, the conclusions should be interpreted liberally.

All of the preserving oils, viz, the products of coal tar, wood tars, water-gas tars, and crude petroleum produced no appreciable weakening in the strength of the wood impregnated with them. The amount of moisture which the treated specimens contained could not be definitely determined, although it is believed that it was slightly less than the moisture in the untreated specimen. The variations in individual cases from the average is within the limit of accuracy of the test. An average of all the tests indicates that the strengths treated and untreated were about the same.

In general, the water-soluble preservatives caused a slight weakening of the seasoned wood. This was most pronounced in the case of sodium silicate and by-product zinc sulphate. The values given for the effect of these preservatives are accentuated, due to the higher moisture content of the treated pieces. The application of a moisture-correction factor would probably show that, with the exception of sodium silicate and by-product zinc sulphate, the weakening caused by the water-soluble preservatives is of no practical significance. The specimens treated with sodium silicate, however, were noticeably affected, the outer wood fibers being badly checked and disintegrated.

PENETRANCE OF THE PRESERVATIVE INTO WOOD.

Table 2 gives the results obtained on the penetrance of the preservative into wood.

So far as penetrance is concerned, the following preservatives can be considered satisfactory: Coal-tar creosote, coal-tar creosote fractions I, II, III, and IV, the three water-gas-tar creosotes, S. P. F. and Avenarius carbolineums, C. A. wood preserver, beechwood creosote, Spirittine, wood-creosote oil, copperized oil, fuel oil, kerosene, zinc chloride, commercial zinc sulphate, by-product zinc sulphate, B. M. preservative, sodium fluoride, and cresol calcium.

Wood tar from Douglas fir, Preservol, and coal-tar creosote fraction V were very difficult to force through hemlock, being more than twice as resistant as coal-tar creosote.

Satisfactory penetrations with hardwood tar, Timberasphalt, and sodium silicate were not secured. The results indicated that they were from 10 to 18 times as resistant to penetration into hemlock as the coal-tar creosote used.

PERMANENCE OF THE PRESERVATIVE AFTER INJECTION INTO WOOD.

Table 3 gives the results obtained from the volatility tests.

After 10 weeks' exposure the preservatives had lost amounts varying from 1 to nearly 60 per cent. The loss was proportional to the content of low-boiling oils, as shown by analysis, those having low distillation points losing the most by volatilization.

The oils losing excessively by volatilization were the first two fractions of coal-tar creosote, water-gas-tar creosote (specific gravity 1.012), and kerosene. The high volatility of these oils separates them from the more efficient wood preservatives.

Those losing moderately by volatilization were coal-tar creosote fractions III and IV, coal-tar creosote, water-gas-tar creosote (sp. gr. 1.051), wood tar from Douglas fir, wood-creosote oil, beechwood creosote, Preservol, and fuel oil.

The least volatile of the oils tested were coal-tar creosote fraction V, water-gas-tar creosote (specific gravity 1.07), Avenarius carbolineum, S. P. F. carbolineum, C. A. wood preserver, hardwood tar, Spirittine, and Timberasphalt. Some difficulty was experienced in obtaining reliable data upon these oils, due to their nonvolatile character. There was a tendency for the specimens to absorb small quantities of moisture, which obscured the results somewhat. The data show, however, that the oils just mentioned were much less volatile, and therefore more permanent in the wood exposed to the air than those listed in the two preceding paragraphs.

The lighter fractions of coal-tar creosote were more highly toxic than the very heavy fractions. It is especially necessary in the case of oils, therefore, that the toxic properties should be considered in conjunction with the permanence of the preservative. The higher toxicity and greater volatility of low-boiling creosote oils and the lower toxicity and lower volatility of the high-boiling creosote oils tend to balance each other. This point has been substantiated in service tests in which coal-tar creosote proved practically as efficient in preventing decay as the higher boiling creosote derivatives.[1]

EFFECT OF THE PRESERVATIVE ON THE COMBUSTIBILITY OF WOOD.

Table 4 gives the results obtained in the inflammability tests.

Wood treated with the oils in every case ignited at lower temperatures than untreated wood. When permitted to air-season for

[1] See article Eng. News, Nov. 27, 1913, "Condition of experimental poles in the Augusta-Savannah and Helena-Meldrim lines," and Forest Service Circular 198.

3 months the temperature of ignition was considerably raised, due probably to the evaporation of the more volatile constituents. The loss in weight from burning treated wood seasoned for 3 months was also usually less than in the specimens burned shortly after impregnation.

In general, wood treated with oils ignited at lower temperatures than wood treated with water-soluble preservatives. The temperature of ignition in both cases was lower than that of untreated wood.[1] Furthermore, wood treated with oils showed in general greater loss in weight after combustion than wood treated with the water-soluble salts. It should be noted, however, that the amount of wood actually burned may have been less than in the case of the salts.

Untreated wood and wood treated with oils (exception, Timber-asphalt) burned freely, and in general had to be extinguished after a three-minute period, while wood treated with water-soluble salts (exception, cresol calcium) burned slowly and became extinguished in less than three minutes.

TOXIC EFFICIENCY OF THE PRESERVATIVE IN INHIBITING FUNGOUS GROWTH.

Table 5 [2] contains the results of the tests thus far completed on toxicity. The following conclusions on the toxicity of the various preservatives should not be considered as absolutely final, because of errors peculiar to the Petri-dish method.

The products obtained from the high-boiling constituents of coal-tar creosote, for example, the carbolineums and high-boiling creosote fractions, were much less toxic than the coal-tar creosote or the low-boiling fractions. The products with the greater toxic properties are those having the lower specific gravities and lower boiling points.

The same was true to an exaggerated degree in the water-gas-tar creosotes, the 1.012 oil being about as toxic as coal-tar creosote, while the 1.07 oil was only slightly toxic.

The hardwood tar and Spirittine (from yellow pine) were less than half as toxic as coal-tar creosote. Wood tar from Douglas fir and Preservol were about equal to coal-tar creosote in toxicity. Beech-wood creosote was more than twice as toxic as coal-tar creosote.

Of the water-soluble salts tested sodium fluoride was the most highly toxic, being from one and one-half to two times as toxic as coal-tar creosote. Zinc chloride was slightly more toxic to *Fomes annosus*, but far less toxic to *Fomes pinicola* than coal-tar creosote. Cresol calcium was also very highly toxic, being from two to four

[1] Wood dipped in a 50 per cent sodium silicate solution ignited at a temperature of 448° C., and its weight was reduced 17 per cent, although burning immediately ceased when the sample was dropped in the lower chamber of the inflammability apparatus.

[2] This table was published in the Jour. Ind. and Eng. Chem., Feb., 1914, by C. J. Humphrey and Ruth Fleming, who conducted the tests. They are included here because they are an important factor in determining the value of these preservatives.

times as much so as coal-tar creosote. Sapwood antiseptic was almost nontoxic.

Preservatives designated as copperized oil, fuel oil, Timberasphalt, kerosene, and N. S. Special had very low toxic properties.

CORROSIVE ACTION OF THE PRESERVATIVE ON FLANGE STEEL.

Of the various preservatives tested, coal-tar creosote, copperized oil, the fractions of coal-tar creosote, the various carbolineums, the water-gas-tar products, fuel oil, Timberasphalt, and kerosene had very slight corrosive action on steel. In practical operations such action can very probably be neglected.

The metallic salts, except cresol calcium and sodium fluoride, were much more pronounced in their action than coal-tar creosote, so that the depreciation in plants using them would seem to be much greater. The corrosive action of cresol calcium is much less than the other salts tested. Zinc sulphate was much less corrosive than zinc chloride.

The very marked corrosion of hardwood tar, Preservol, and tar from Douglas fir is probably due to the comparatively large amount of acetic and other organic acids which they contain, while the somewhat less corrosive action of Spirittine and beechwood creosote are probably due to smaller quantities of these acids.

In general, wood-tar products were much more corrosive than coal-tar or petroleum products. This property may, however, be largely eliminated in the future development in methods of refining these oils.

DISCOLORATION OF PAINTED WOOD.

All of the oils tested rendered the wood unfit for subsequent painting.[1] Copperized oil was least objectionable in this respect. If thoroughly dried after treatment, so that excess oil would not appear on the surface, it is possible that wood treated with some of these preservatives could be satisfactorily painted with dark pigments.

The water-soluble salts were all satisfactory (except sodium silicate and cresol calcium) in that they caused no discoloration and apparently no deterioration of the painted surface. From the results of tests thus far made it is likely that woods treated with zinc chloride and many water-soluble salts can be successfully painted.

Cresol calcium caused discoloration of the paint; sodium silicate reacted with the oil of the paint film, causing it to lose its adhering properties.

Additional tests on the effect of zinc chloride and sodium fluoride on white-lead paint were made. Specimens exposed to the weather were in good condition after 2½ months, when they were accidentally destroyed. Specimens placed in moist air were in good condition after 1 year and 4 months. No difference was noticeable between

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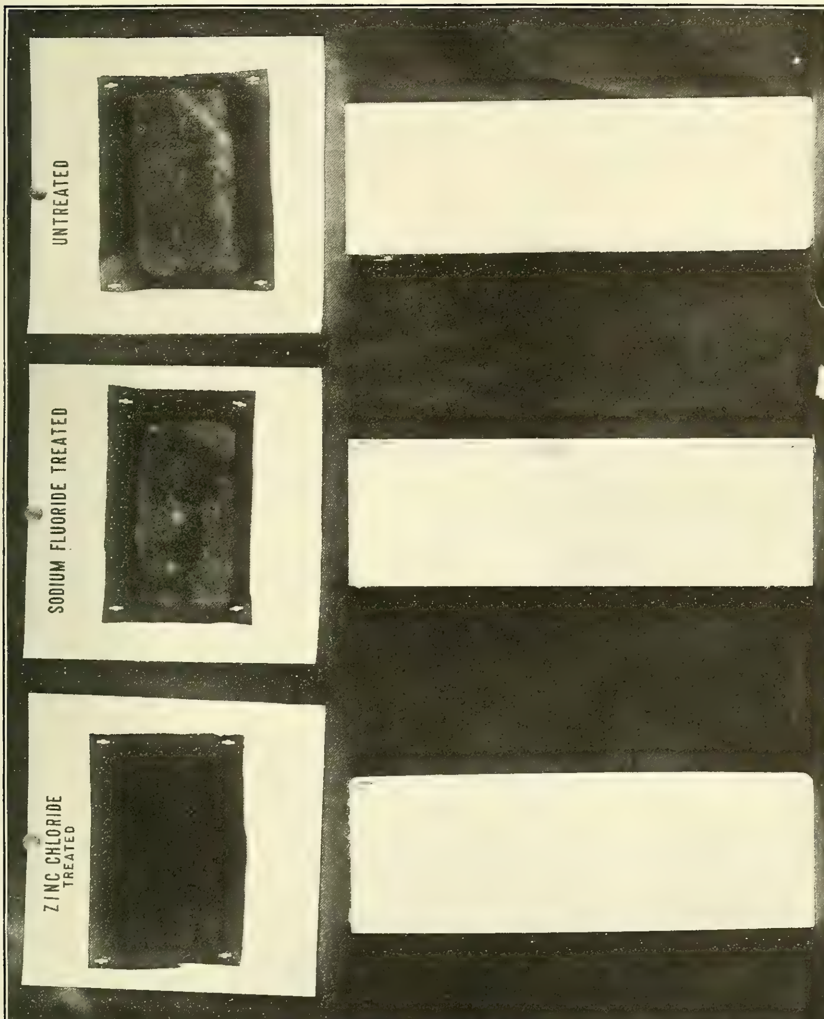
[1] This applies, of course, only to the method of painting herein described.



EFFECT OF TREATMENT ON PAINT COATINGS.

[Specimens immersed in water at 70° F. for 1 year and 4 months. Upper portion shows degree of chalking of paint when rubbed with a dark cloth.]

the treated and untreated specimens; there was no visible evidence of the hygroscopic action of zinc chloride on the paint film, nor did the salt appear to come to the surface. There was a marked difference in the appearance of the treated and untreated specimens that were placed in running water for 1 year and 4 months. (See Pl. VI.) The paint film on the one treated with sodium fluoride and the untreated one had disintegrated and could be rubbed off upon a cloth (see Pl. VI, at top); that on the specimen treated with zinc chloride was in good condition. This indicates that zinc chloride may have a preservative action upon paint films under certain circumstances.

No results have thus far been obtained from the last series of tests made in cooperation with the National Paint Manufacturers' Association.

The results of the tests thus far made indicate that woods treated with zinc chloride, sodium fluoride, and other water-soluble salts might be successfully painted. This point can not be definitely settled, however, until the results of the tests in cooperation with the National Paint Manufacturers' Association become available.

CONCLUSIONS.

In general, highly viscous oils do not readily penetrate, while oils with low viscosities penetrate wood readily. As temperature strongly influences the viscosity of oils, and as the diffusion of the preservative through the wood is one of the most important factors in proper treatment, to secure best results both the wood and the preservative should be sufficiently heated during the pressure period. Because of the low thermal conductivity of wood the treatments should not be made too rapidly. With water-soluble salts these precautions are not important.

With coal-tar creosote it appears that the fractions of greater stability are the less toxic. Present practice rather favors the retention in treated wood of the more volatile fractions by an admixture of the more stable ones. If the toxic values here given are correct, there is, in practice, being forced into wood about one and one-half times as much zinc chloride and from 10 to 20 times as much coal-tar creosote as is necessary to prevent decay. Of course, in practice more preservative than these toxic minima must be forced into wood in order to make proper allowance for any subsequent changes that might take place. However, more economic results, especially when decay is accompanied by mechanical deterioration, can be secured by diffusing the preservative more thoroughly through the wood than by saturating the outer fibers and attempting to retain in the wood the volatile constituents through admixtures of nonvolatile constituents. It also appears that the factor of safety in zinc-chloride treatments is very low, and that to secure the best results more than 0.4 to 0.5 pound per cubic foot, the present practice, should be injected.

In general, the flash or burning point of an oil affects the inflammability of wood treated with it. Of greater importance, however, is the length of time the treated wood has seasoned, as a prolonged seasoning of such wood raises considerably its ignition temperature. It would seem good practice first to season such treated timber before placing it in positions subject to fire. While wood treated with the water-soluble salts mentioned in these tests was in general less difficult to ignite than untreated wood, nevertheless the presence of such preservatives usually renders the wood slow burning and easily extinguishable.

In using the data submitted in this bulletin, the reader is cautioned against drawing sweeping conclusions. It was possible to make only a limited number of check determinations because of the many variables which had to be considered. The most reliable information on the efficiency of preservatives is, of course, obtained from service tests, but until such data become available, it is thought that the tests already described will be found valuable in studying the most efficient use of wood preservatives.

TABLE 1.—*Physical and chemical properties of the preservatives.*

Preservative No.	Preservative designated by cooperator as—	Specific gravity.	Temperature at specific gravity.	Flash point.	Burning point.	Viscosity temperature (° C.).				Odor.	Remarks.
						10	30	50	95		
			° C.	° C.	° C.						
1	Coal-tar creosote	1.048	60	93	100	3.10	1.70	1.40	1.10	Strong creosote	Graded as C.
2	Coal-tar creosote, Fraction I	0.934	60	62	69		1.10	1.00	.95	Like toluene	Includes oils distilling between 0° and 205° C.
3	Coal-tar creosote, Fraction II	1.003	60	79	85				1.00	Strong like naphthalene	Includes oils distilling between 205° and 250° C. Solid at room temperature.
4	Coal-tar creosote, Fraction III	1.045	60	103	110	2.45	1.40	1.20	1.10	Strong coal-tar creosote	Includes oils distilling between 250° and 295° C.
5	Coal-tar creosote, Fraction IV	1.088	60	130	136			1.51	1.11	Mild coal-tar creosote	Includes oils distilling between 295° and 320° C. Would not flow at 30° C.
6	Coal-tar creosote, Fraction V	1.150	60	172	178			80.00	2.60	do	Includes residue above 320° C.
7	Water-gas-tar creosote, 1.051	1.042	60	72	93		1.70	1.40	[1] 1.10	Like illuminating gas	A distillate of water-gas tar.
8	Water-gas-tar creosote, 1.012	0.985	60	81	93		1.20	1.10	[2] 1.00	do	Do.
9	Water-gas-tar creosote, 1.070	1.058	60	48	65	16.00	3.70	2.00	1.20	Like kerosene	A water-gas-tar product.
10	S. P. F. carbolineum	1.127	16	133	157		4.40	2.30	1.25	Tarry (mild)	These compounds are similar in many respects.
11	Avenarius carbolineum	1.126	16.5	139	166		7.50	2.40	1.25	Tarry	
12	C. A. wood preserver	1.120	60	142	165		5.50	2.00	1.10	Not distinctive	High-boiling coal-tar products.
13	Hardwood tar	1.195	60	90	(3)		17.50	6.30	1.40	Disagreeable pyroligneous.	
14	Wood tar (Douglas fir)	1.052	60	45	85		15.20	4.90	1.40	do	This resembles a tar more than a creosote.
15	Beechwood creosote	1.040	60	88	96	[4] 5.80	3.40	1.90	1.20	Like pyroligneous acid	A refined product of beechwood tar. Contained 3.2 per cent tar acids.
16	Spirittine	1.006	60	74	77		4.20	1.90	1.20	do	A product of the distillation of southern pine.
17	Preservol	1.170	60	(5)	(5)		(6)	5.90	1.50	do	Hardwood tar dissolved in water-contained pyroligneous acid.
18	Wood-creosote oil	1.032	60	87	94		4.70	1.90	1.20	do	A product of the distillation of southern pine.
19	Timberasphalt	1.063	60	240	260			99.20	5.20	Like crude oil	A residuum of petroleum.
20	Copperized oil	0.937	25	125	164		18.00	5.10	1.50	Like crude oil (mild)	Contains 0.34 per cent copper.
21	Fuel oil	0.870	60	72	101	2.80	1.57	1.30	1.10	Like crude oil (strong)	A crude petroleum.

[1] 80° C.
[2] 85° C.
[3] Water boiled off, preventing burning.
[4] At 22° C.
[5] Not possible because of presence of 50 per cent water.
[6] Would not run at 27° C. Lowest temperature at which viscosity could be taken was 43° C., giving 7.9 viscosity at 70° C.—2.2.

TABLE 1.—*Physical and chemical properties of the preservatives*—Continued.

Preservative No.	Preservative designated by cooperator as—	Specific gravity.	Temperature at specific gravity.	Flash point.	Burning point.	Viscosity temperature (° C.).				Odor.	Remarks.
						10	30	50	95		
			°C.	°C.	°C.						
22	Kerosene	0.798	60	57	61	......	1.10	1.00	0.90	Characteristic	A product of petroleum.
23	Zinc chloride	1.028	20	......	......	......	......	......	......	Odorless	Contained 2.67 per cent zinc chloride.
24	Zinc sulphate	1.033	20	......	......	......	......	......	......	do	Contained 5.9 per cent zinc sulphate $7H_2O$.
25	Zinc sulphate (by-product)	1.040	20	......	......	......	......	......	......	do	Contained 6.8 per cent zinc sulphate $7H_2O$.
26	B. M. preservative	1.025	20	......	......	......	......	......	......	do	Contained 0.93 per cent Al. sulphate, 1.8 per cent $ZnCl_2$.
27	Sapwood antiseptic	1.027	20	......	......	......	......	......	......	do	Contained 2.92 per cent NaCl, 0.246 per cent $CaSO_4$, 0.246 per cent $ZnSO_47H_2O$, 0.182 per cent $CuSO_45H_2O$, .06 per cent $FeSO_44H_2O$.
28	Sodium silicate	1.074	20	......	......	......	......	......	......	do	Contained 8.9 per cent sodium silicate.
29	Sodium fluoride	1.009	20	......	......	......	......	......	......	do	Contained 1.2 per cent sodium fluoride.
30	Cresol calcium	1.075	20	......	......	......	......	......	......	Like phenols	2.43 per cent cresol calcium solution.

TABLE 2.—*Penetrance of the preservatives and their effect on the strength of wood.*

Preservative No.	Preservative designated by cooperator as—	Penetration.				Average absorption of preservative per cubic foot.	Strength in per cent of modulus of rupture of untreated wood.	Moisture at test.	
		Radial and tangential.		Longitudinal.[1]				Untreated.	Treated.
		Maximum.	Minimum.	Maximum.	Minimum.				
		Inch.	*Inch.*	*Inches.*	*Inches.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Coal-tar creosote	0.28	0.23	6.00	5.30	8.76	93	6.20	....
2	Coal-tar creosote, Fraction I.	.45	.21	6.00	6.00	5.28	101	5.88	....
3	Coal-tar creosote, Fraction II.	.45	.17	6.00	6.00	6.86	92	6.22	....
4	Coal-tar creosote, Fraction III.	.45	.21	6.00	6.00	7.55	92	6.44	....
5	Coal-tar creosote, Fraction IV.	.37	.18	6.00	5.50	7.33	96	6.43	....
6	Coal-tar creosote, Fraction V.	.12	.07	3.80	1.20	2.00	90	6.29	....
7	Water-gas-tar creosote, 1.051.	.45	.33	6.00	5.00	6.45	92	5.53	....
8	Water-gas-tar creosote, 1.012.	.45	.42	6.00	5.30	7.18	90	6.18	....
9	Water-gas-tar creosote, 1.070.	.10	.10	6.00	3.33	9.58	108	4.52	....
10	S. P. F. carbolineum.	.37	.23	6.00	5.70	8.77	100	6.40	....
11	Avenarius carbolineum.	.17	.12	6.00	5.30	8.08	109	6.81	....
12	C. A. wood preserver.	.27	.20	6.00	4.70	8.43	100	6.99	....
13	Hardwood tar	.03	.03	.92	.50	6.50	98	6.11	....
14	Wood tar (Douglas fir).	.08	.08	3.58	2.33	2.82	107	5.80	....
15	Beechwood creosote.	.36	.106	6.00	3.16	12.68	99	5.30	....
16	Spirittine	.38	.18	6.00	4.50	8.09	96	6.95	....
17	Preservol	.08	.05	3.75	1.50	6.27	107	6.24	....
18	Wood-creosote oil	.37	.15	6.00	4.30	12.86	110	6.41	....
19	Timberasphalt	.02	.02	.33	.33	5.68	106	6.68	....
20	Copperized oil	.22	.22	6.00	4.08	8.58	101	5.49	....
21	Fuel oil	.45	.43	6.00	6.00	12.70	117	....	....
22	Kerosene	.45	.30	6.00	6.00	14.51	90	5.18	....
23	Zinc chloride	.10	.08	6.00	5.30	[2] .43	88	7.13	9.35
24	Zinc sulphate	.10	.08	6.00	4.66	[3] .96	89	5.14	9.60
25	Zinc sulphate (by-product).	.25	.17	6.00	4.66	[3] 1.11	82	3.88	5.77
26	B. M. preservative	.13	.10	6.00	4.60	[3] .50	85	5.16	9.48
27	Sapwood antiseptic	....	....	....	....	....	....	....	....
28	Sodium silicate	.05	.03	.46	.30	.99	82	6.42	7.38
29	Sodium fluoride	.10	.10	6.00	5.00	.20	85	5.82	8.70
30	Cresol calcium	.10	.10	6.00	3.30	.46	103	5.72	6.58

[1] A penetration of 6 inches was the maximum that could be secured longitudinally, 0.45 inch was the maximum radial and tangential. The absorptions here given have no reference to the data on penetrance.
[2] Dry salt. [3] For composition see Table 1.

TABLE 3.—*Permanence of the preservatives after injection into wood.*

Preservative No.	Preservative designated by cooperator as—	Volatility. Per cent volatilized after seasoning for—					
		10 days.	20 days.	30 days.	50 days.	70 days.	90 days.
1	Coal-tar creosote	11	15	17	20	22	....
2	Coal-tar creosote, Fraction I.	38	48	53	57	57	....
3	Coal-tar creosote, Fraction II.	22	30	36	44	47	....
4	Coal-tar creosote, Frac. III	13	21	28	34	37	....
5	Coal-tar creosote, Fraction IV	8	11	14	18	20	....
6	Coal-tar creosote, Fraction V	6	6	5	6	7	....
7	Water-gas-tar creosote, 1.012.	16	26	32	41	45	....
8	Water-gas-tar creosote, 1.051.	18	21	25	30	33	....
9	Water-gas-tar creosote, 1.07	2	3	3	4	5	....
10	S. P. F. carbolineum	3	4	5	8	11	....
11	Avenarius carbolineum.	....	....	....	1	1	....
12	C. A. wood preserver	−2	−2	....	+1	+1	....
13	Hardwood tar	....	....	2	6	6	....
14	Wood tar (Douglas fir)	12	14	15	15	14	....
15	Beechwood creosote	14	17	21	25	29	....
16	Spirittine	1	3	5	7	8	....
17	Preservol	11	15	16	16	17	....
18	Wood-creosote oil	11	13	15	16	16	....
19	Timberasphalt	....	....	−12	+1	0	....
20	Copperized oil	5	5	5	5	4	....
21	Fuel oil	2	4	7	11	13	....
22	Kerosene	55	74	81	88	91	....

TABLE 4.—*Inflammability of treated wood.*

Preservative No.	Preservative designated by cooperator as—	Temperature of ignition (° C.). Days after impregnation— 2	Temperature of ignition (° C.). Days after impregnation— 90	Loss in weight due to burning calculated in per cent of weight before ignition. Days seasoned— 2	Loss in weight due to burning calculated in per cent of weight before ignition. Days seasoned— 90	Character of combustion.
	Untreated wood (hemlock)	320	......	29	......	Burned freely.
1	Coal-tar creosote	174	225	25	21	Burned freely; black smoke; easily extinguished.
2	Coal-tar creosote, Fraction I	133	306	23	33	Burned very freely; easily extinguished.
3	Coal-tar creosote, Fraction II	113	286	25	21	Burned freely; easily extinguished.
4	Coal-tar creosote, Fraction III	148	269	26	16	Did not burn as well as creosote; easily extinguished.
5	Coal-tar creosote, Fraction IV	183	223	33	21	Burned freely; extinguished with difficulty.
6	Coal-tar creosote, Fraction V	195	287	10	15	Ignited with difficulty; burned poorly; easily extinguished.
7	Water-gas-tar cresote, 1.051	172	231	24	19	Did not burn freely; easily extinguished.
8	Water-gas-tar creosote, 1.012	149	238	29	18	Burned freely; difficult to extinguish.
9	Water-gas-tar creosote, 1.070	231	243	40	31	Burned like Avenarius carbolineum.
10	S. P. F. carbolineum	243	263	26	19	Burned like coal-tar creosote, but not so freely.
11	Avenarius carbolineum	213	235	32	18	Do.
12	C. A. wood preserver	215	247	33	35	Burned like creosote.
13	Hardwood tar	190	241	29	30	Burned freely; dense black smoke.
14	Wood tar (Douglas fir)	167	217	36	26	Burned like coal-tar creosote.
15	Beechwood creosote	177	......	34	19	Burned freely; black smoke; rather easy to extinguish.
16	Spirittine	194	247	37	29	Burned freely; difficult to extinguished.
17	Preservol	205	269	23	22	Did not burn as well as creosote; easily extinguished.
18	Wood-creosote oil	178	251	39	35	Burned very freely; very difficult to extinguish.
19	Timberasphalt	296	310	28	32	Did not burn freely.
20	Copperized oil	200	228	43	33	Burned like coal-tar cresote.
21	Fuel oil	167	241	36	27	Burned very freely; very difficult to extinguish.
22	Kerosene	126	231	37	17	Do.
23	Zinc chloride	......	[1] 287	......	19	Hard to ignite; burned poorly; easily extinguished.
24	Zinc sulphate	......	[1] 304	......	18	Do.
25	Zinc sulphate (by-product)	......	[1] 298	......	......	Do.
26	B. M. preservative	......	[1] 305	......	18	More difficult to burn than zinc chloride.
27	Sapwood antiseptic	......	......	......	......	
28	Sodium silicate	......	[2] 309	......	10	More difficult to burn than B. M. preservative.
29	Sodium fluoride	......	[1] 303	......	25	Burned like zinc chloride.
30	Cresol calcium	......	[1] 288	......	29	Burned freely; white smoke; hard to extinguish.

[1] Woods treated with salts were ignited as soon as their moisture content was reduced by air-seasoning to 6 per cent, usually about 2 weeks after impregnation. For absorption of preservatives, see Table 3.
[2] See footnote 1, page 11.

NOTE.—All salts burned for less than 3 minutes; all oils burned for 3 minutes and were then extinguished.

TABLE 5.—*Toxicity of preservatives to Fomes annosus and Fomes pinicola.*[1]

Preservative No.	Preservative designated by cooperator as—	Killing point. Fomes annosus. Per cent.	Fomes annosus. Pounds per cubic foot of media.	Fomes annosus. Ratio to coal-tar creosote.	Fomes annosus. Ratio to zinc chloride.	Fomes pinicola. Per cent.	Fomes pinicola. Pounds per cubic foot of media.	Fomes pinicola. Ratio to coal-tar creosote.	Fomes pinicola. Ratio to zinc chloride.
1	Coal-tar creosote	0.55	0.343		0.91	0.225	0.140		3.0
2	Coal-tar creosote, Fraction I	.30	.187	1.8		.225	.140	1.0	
3	Coal-tar, Fraction II	.225	.140	2.5		.15	.094	1.5	
4	Coal-tar creosote, Fraction III	[2] .325	.203	1.7		.125	.078	1.8	
5	Coal-tar creosote, Fraction IV	[2] 3.3	2.059	.16		.125	.078	1.8	
6	Coal-tar creosote, Fraction V	33.0	20.59	.017		[2] 7.80	4.867	.029	
7	Water-gas-tar creosote, 1.051	3.0–4.0	1.9–2.5	.18–.14		(3)			
8	Water-gas-tar creosote, 1.012	[4] .60	[4] .375	[4] .9		(3)			
9	Water-gas-tar creosote, 1.070	[5] 40.0	+25.0	—.016		[5] 40.0	+25.0	.0056	
10	S. P. F. carbolineum	2.25	1.404	.24		(3)			
11	Avenarius carbolineum	5.25	3.27	.104		.30	.187	.75	
12	C. A. wood preserver	1.0–1.5	.6–.9	.55–.37		(3)			
13	Hardwood tar	1.25	.78	.44		.75	.468	.30	
14	Wood tar (Douglas fir)	.65	.405	.84		[2] .20	.125	1.12	
15	Beechwood creosote	.12–.24	.075–.15	4.6–2.3		(3)			
16	Spirittine	1.0–2.0	.6–1.2	.55–.27		(3)			
17	Preservol	.70	.437	.8		(3)			
18	Wood-creosote oil	(3)				(3)			
19	Timberasphalt	[5] 40.0	25.00	—.016		(3)			
20	Copperized oil	40.0	24.96	.015		[5] 40.0	+25.0	.0056	
21	Fuel oil	[5] 40.0	+25.0	—.016		(3)			
22	Kerosene	[5] 40.0	+25.0	—.016		(3)			
23	Zinc chloride	.50	.312	1.1		.75	.468	.30	
24	Zinc sulphate (commercial)	[4] .70	[4] .437	[4] .8	[4] .7				
25	Zinc sulphate (by-product)	(3)				(3)			
26	B. M. preservative	(3)				(3)			
27	Sapwood antiseptic	[5] 75.0				(3)			
28	Sodium silicate	(3)				(3)			
29	Sodium fluoride	.25	.156	2.2	2.0	.15	.94	1.5	5.0
30	Cresol calcium (see note)	.14–.28	.087–.174	3.9–2.0	3.6–1.80	(3)			

[1] Part of this table was published by C. J. Humphrey and Ruth Fleming in Jour. Ind. and Eng. Chem., February, 1914.
[2] Killing point has not been checked in duplicate. [3] Tests not completed. [4] Around. [5] Above.

NOTE.—In this table the figures have checked to within an accuracy of 10 per cent or less except those referred to by footnote 2; also in certain cases the killing point has been given as within certain limits, and further work will define these more accurately. Those toxicities indicated as "around" a certain concentration are close to the true value but may fluctuate slightly on either side; where indicated as "above" a certain concentration the result merely indicates that this is the highest concentration yet tested, and the ultimate killing point may be considerably higher. Service tests on cresol calcium have shown poor results to date.

TABLE 6.—*Corrosive action of the preservatives.*

Preservative No.	Preservative designated by cooperator as—	Loss in weight of flange steel after immersion in preservative for 4 weeks at 98° C. in ounces per square foot per week.
1	Coal-tar creosote	Less than 0.005.
2	Coal-tar creosote, Fraction I	Do.
3	Coal-tar creosote, Fraction II	Do.
4	Coal-tar creosote, Fraction III	Do.
5	Coal-tar creosote, Fraction IV	Do.
6	Coal-tar creosote, Fraction V	Do.
7	Water-gas-tar creosote, 1.051	Do.
8	Water-gas-tar creosote, 1.012	Do.
9	Water-gas-tar creosote, 1.07	Between 0.005 and 0.010.
10	S. P. F. carbolineum	Less than 0.005.
11	Avenarius carbolineum	Between 0.010 and 0.025.
12	C. A. wood preserver	Less than 0.005.
13	Hardwood tar	Between 1.900 and 2.000.
14	Wood tar (Douglas fir)	Between 1.200 and 1.300.
15	Beechwood creosote	Between 0.400 and 0.450.
16	Spirittine	Between 0.200 and 0.250.
17	Preservol	Between 1.100 and 1.200.
18	Wood creosote oil	No tests made.
19	Timberasphalt	Between 0.050 and 0.100.
20	Copperized oil	Less than 0.005.
21	Fuel oil	Do.
22	Kerosene	Do.
23	Zinc chloride, 2.4 per cent	Between 0.300 and 0.350.
24	Zinc sulphate, 4.5 per cent	Between 0.100 and 0.150.
25	Zinc sulphate (by-product), 7.2 per cent	Do.
26	B. M. preservative, 2 per cent zinc and 1 per cent alum sulphate	Between 0.700 and 0.750.
27	Sapwood antiseptic	Not tested quantitatively; copper all thrown out in a few minutes.
28	Sodium silicate	Decomposed at temperature of test.
29	Sodium fluoride, 1 per cent	Between 0.025 and 0.050.
30	Cresol calcium	Less than 0.005.

TABLE 7.—*Discoloration of wood treated with preservatives and painted.*

Preservative No.	Preservative designated by cooperator as—	Condition of painted surface after exposure for 1 month.
1	Coal-tar creosote	Very badly discolored and paint not dry.
2	Coal-tar creosote, Fraction I	Slightly yellow in spots; paint dry.
3	Coal-tar creosote, Fraction II	Very badly discolored; paint nearly dry.
4	Coal-tar creosote, Fraction III	Do.
5	Coal-tar creosote, Fraction IV	Do.
6	Coal-tar creosote, Fraction V	Very badly discolored; paint not dry.
7	Water-gas-tar creosote, 1.051	Very badly discolored, and sticky in spots.
8	Water-gas-tar creosote, 1.012	Slightly discolored; paint somewhat sticky.
9	Water-gas-tar creosote, 1.070	Very badly discolored; paint not dry.
10	S. P. F. carbolineum	Do.
11	Avenarius carbolineum	Do.
12	C. A. wood preserver	Do.
13	Hardwood tar	Do.
14	Wood tar (Douglas fir)	Do.
15	Beechwood creosote	Discolored gray; oil penetrated paint coating in several places.
16	Spirittine	Slightly discolored; paint sticky in spots.
17	Preservol	Paint discolored and collected in spots, leaving surface partly bare; still very wet.
18	Wood creosote oil	Badly discolored; paint not dry.
19	Timberasphalt	Very badly discolored; paint dry, but did not stick to wood.
20	Copperized oil	Discolored; paint somewhat sticky.
21	Fuel oil	Slightly yellow in spots; paint slightly sticky.
22	Kerosene	Slightly yellow in spots; paint dry.
23	Zinc chloride	Appearance similar to untreated specimen.
24	Zinc sulphate	Do.
25	Zinc sulphate (by-product)	Do.
26	B. M. preservative	Do.
27	Sapwood antiseptic	No test made.
28	Sodium silicate	Slightly discolored.
29	Sodium fluoride	Appearance similar to untreated specimen.
30	Cresol calcium	Discolored, pale yellow, and somewhat sticky.

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Contribution from the Office of Markets, Charles J. Brand, Chief.
September 25, 1914.

ECONOMIC CONDITIONS IN THE SEA ISLAND COTTON INDUSTRY.

By WILLIAM R. MEADOWS, *Cotton Technologist.*

INTRODUCTION.

At the request of the farmers living in the neighborhood of Charleston, S. C., forwarded through the Chamber of Commerce of Charleston to the Department of Agriculture, an investigation of the market and economic conditions in the Sea Island cotton industry was made by the Office of Markets during August and September, 1913. The extremely low price that prevailed, which was probably below the cost of production, the large stock carried over into the succeeding year in spite of the very small crop, the indifference of buyers due to lack of orders, indicated a condition of crisis which called for a thorough examination of, and an impartial report on, the condition of the industry. The field of this investigation was not limited to Charleston and the islands adjacent thereto, but was extended to include the Sea Island cotton districts of Georgia and Florida and to nearly all the American mills that spin yarns from this kind of cotton. Although Carolina Sea Island cotton is nearly all exported, it was impracticable to visit foreign countries to interview the manufacturers using it, hence this report does not cover completely the consumption of the Carolina crop.

The object of this paper is to set forth as concisely as possible the results of this investigation. It is in no sense a treatise on agriculture.[1]

STATISTICAL REVIEW.

A study of the tables in the appendix to this report indicates that the unsatisfactory condition of the Sea Island trade was due to underconsumption rather than to overproduction. By reference to Tables I and III, it will be seen that the crop of 1911–12 was 122,744 bales,[2]

[1] Those interested in the agricultural phases of the subject are referred to Farmers' Bulletin 302, U. S. Dept. Agr., by W. A. Orton, entitled "Sea Island Cotton: Its Culture, Improvement, and Diseases."

[2] Gordon's figures obtained from Table I of appendix.

NOTE.—This bulletin discusses the economic conditions in the Sea Island cotton industry in South Carolina and the islands off the coast and also in portions of Georgia and Florida.

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averaging about 400 pounds each, which is next to the largest yield on record; that the average price per pound for Georgias and Floridas was 20.41 cents [1] and for South Carolinas 23.73 cents; that consumption was unprecedented at 123,145 bales,[2] and that the season ended with a small stock, 5,533 bales,[3] carried over.

The crop of 1912–13 was only 73,777 bales, averaging about 382 pounds each, of which only about 68,080 [3] reached the chief interior markets and seaports. The average price of Georgias and Floridas was 19.50 cents and for South Carolinas 25 cents. Consumption was only 58,019 bales,[2] and the stock at the end of the season stood at the highest figure on record, 15,639 bales.[3]

It will be noted that the crop of 1912–13 was, roughly, three-fifths of that of the preceding year, that prices were lower, and that exports decreased fully 20 per cent from those of the previous year. Attention is called especially to the fact that the American takings of Sea Island for 1911–12 were 102,846 bales,[3] against 41,899 [3] for 1912–13, a decrease of nearly 60 per cent within a year. When calculated on the percentage of the entire Sea Island crop purchased by American mills, the takings show 83.79 per cent for 1911–12 against 56.79 per cent during 1912–13.

EGYPTIAN COMPETITION.

A glance at Table IV, which shows the imports of Egyptians into the United States, will demonstrate that no great increase has been made in the importation of that cotton by domestic mills. While the year 1912–13 exhibits an increase of about 6,400 bales over the year before, imports are 1,548 bales less than in 1910–11. In other words, the importations of Egyptian cotton into the United States were practically uniform during the past three years.

As Egyptian bales usually weigh about 750 pounds each, while Sea Island bales average only 382, it is necessary to reduce both kinds of bales to a common unit of weight for the purposes of comparison and addition. Accordingly, the usual 500-pound bale has been adopted. Table V is presented in this connection and shows the actual consumption of the various commercial varieties of cotton in the United States for the years 1911, 1912, and 1913. It is difficult to reconcile this table with the tables showing spinners' takings, and no attempt is here made to do so, but the figures of Table V are accepted as true and accurate, as they were issued by the Census Bureau after careful investigation. From this table it may easily be determined that the total consumption of Sea Island and Egyptian for 1912–13 was 243,118 equivalent 500-pound bales, against 256,293 for the year 1911–12, thus showing a decrease of 13,175 bales in the consumption of extra-long staple in the United States during 1912–13.

[1] All figures, unless otherwise specified, are from Census Bureau.
[2] Obtained by adding American consumption and exports; Gordon's figures.
[3] Gordon's figures obtained from Table I of appendix.

During this same year the consumption of Egyptian increased practically 21,000 bales (500-pound equivalent), and consequently it may be concluded that not only the entire loss in consumption of extra-long staples but the increase in Egyptian was at the expense of Sea Island.

CAUSES OF DECREASED CONSUMPTION.

In looking for the causes of this lack of consumption many reasons have been advanced by those engaged directly in growing or in selling or in manufacturing Sea Island cotton. The reasons given by different interests sometimes conflict, and mistaken ideas have been advanced in a few instances, but there is substantial agreement among all interested parties as to the essential facts in the case.

There is room for a difference of opinion as to the relative importance of the different causes for the falling off in demand for extra-long staple, but it seems reasonable that all of the following causes have contributed toward the diminished use of Sea Island cotton:

(1) *The deadlock of 1912–13.*—In dealing in Sea Island cotton there is no "futures" market, as there is for Upland or Egyptian. Spinners desiring to purchase their supplies against sales of yarn, which are frequently made for a year in advance, must buy Sea Island cotton outright, or else find some dealer who is willing to assume that risk, and sell contracts for the delivery of a definite number of bales per month during the time covered by the agreement.

In September and October of 1912, early in the cotton season, spinners were buying Sea Island at the prices then prevailing, paying about 23 cents for Extra Choice Georgias. The demand was not strong, but the crop was late and there was no pressure to sell, so prices were easily maintained. Then in November came the Census Bureau's report indicating a crop of approximately 70,000 bales for the year. The better-informed farmers and small dealers decided that the crop was short and that the price would advance, so they resolved to hold for higher prices, which resulted in an immediate advance in the primary asking price of 2 or 3 cents per pound. Accordingly, the cotton buyers and exporters found themselves unable to buy cotton at the price which spinners were willing to pay, and they therefore refused to sell spots or to make contracts with mills for future delivery at the prices which millmen offered. In short, there developed a deadlock in the market beginning in November which lasted until early spring.

The spinners, who considered their margin of profit as already narrow, regarded this advance as an imposition on them by speculators and turned to other sources to look for their supply of raw material. They had already been experimenting with the new Egyptian variety known as Sakellaridis, and naturally turned to that and to brown Egyptian for their supplies of cotton. They bought not only for their immediate needs, but in many cases for 6, 8, and 12 months in advance, thus closing the usual outlet for Sea Island.

There is no doubt that spinners felt that they had a just cause of complaint against the holders of Sea Island cotton, and that they acted more or less in the same way in protecting themselves from the danger which seemed to them to threaten their business, but sufficient evidence has not developed to sustain the charge that spinners united to fix prices. From their point of view, the spinners had Egyptian cotton offered in quantities to supply their year's needs and at prices and on terms more satisfactory than those offered by the holders of Sea Island, so the spinners bought the Egyptian cotton and left the holders of Sea Island free to find whatever market they could for their commodity. This market did not develop before the end of the season, September 1, 1913, and in spite of the short crop of only 73,777 bales, more Sea Island cotton than ever before was carried over into the new crop year.

(2) *The competition of Sakellaridis.*—Aside from any hitch in the usual methods of buying and selling Sea Island such as occurred during 1912–13, it was bound to meet sooner or later the competition of the new Egyptian variety known as Sakellaridis. This variety is more similar to Sea Island than are most other varieties of Egyptian cotton, and is more vigorous and productive than Sea Island. Its staple is about 1½ inches in length, and it is comparatively uniform; it is somewhat coarser than Sea Island and does not mercerize as well; it is harsher and less elastic, but it has fully as much strength as a good quality of Georgias and is decidedly stronger than the lower grades of American Sea Island. Where strength is the chief element to be desired in a yarn or cloth, as in sewing thread or tire cloth, Sakellaridis seems now to be preferred, but in mercerized goods and in high-grade hosiery and underwear Sea Island is still commonly used. At the beginning of the deadlock in November, 1912, Sakellaridis was about 2 cents cheaper than Sea Island; on August 30, 1913, it was being quoted at 3 cents above Georgias and Floridas. The following are some of the reasons given by spinners for preferring Sakellaridis to Sea Island:

(*a*) It is manufactured with less waste than the corresponding grade of Sea Island, usually some 4 or 5 per cent.

(*b*) It works better in the card room, but some spinners claim that this advantage is offset by less production in the spinning room.

(*c*) It makes stronger yarn and stronger cloth.

(*d*) It is bought on a net weight basis, and is paid for 10 days after the receipt of the cotton. Sea Island is sold on gross weight and usually f. o. b. cars at southern markets, with sight draft attached to invoice. This results in its being paid for about 30 days before it is received at the New England mills.

(*e*) Having once introduced Sakellaridis cotton to make a given line of goods, it is a hard matter to change to another cotton which may be just as good. The customer usually grows suspicious when the mill changes the appearance of its goods, and he must be argued with and coaxed into taking the goods. For this reason, if for no other, a mill prefers to run on the same kind of cotton all the time, and it is as difficult to turn back to Sea Island as it was to turn from Sea Island to Sakellaridis.

(3) *The deteriorated quality of Sea Island cotton.*—Another cause for the lessened use of Sea Island is that its quality is not so uniform and good as it was formerly. "It has run down." That it has deteriorated is admitted on all sides. There can be no question of the fact. Some of the causes of this deterioration are not hard to discover, while perhaps others have escaped notice. The most serious cause of deterioration in the interior regions has been the refusal of the Carolina growers to sell planting seed to others. This decision not to sell planting seed came about as the natural result of the situation in which the planters found themselves. In 1902 the culture of Sea Island cotton was introduced in the West Indies. Seed was bought from the best Carolina plantations, and some of the expert Carolina growers were hired to teach the people of St. Vincent, Antigua, the Barbados, and other islands how to raise and prepare this crop for market. The effort to grow the cotton in the West Indies was successful beyond expectations, and within five or six years the Carolina farmers commenced to feel the West Indian competition. They resolved to quit selling seed to anyone—not only to the West Indies, Florida, and Georgia, but also to their fellow islanders. The small farmer on the islands, if his seed was not good, could not buy the better quality or the more prolific seed of his neighbor. He was forced to plant such seed as he had, be it ever so inferior, or else to turn to Upland cotton or to truck crops. As a matter of fact, many farmers have turned largely to Upland cotton. James Island, S. C., had more than 100 acres planted in Upland cotton in 1913. Johns Island and Wadmalaw Island had more than half of their cotton land planted in Upland seed, and Edisto Island had nearly as much Upland as Sea Island planted. Here at the fountainhead of Sea Island culture short cotton had been introduced and was being grown in adjoining fields and in many instances in the same field. Cross pollenization by various means, including bees and other insects, rendered it practically impossible to keep varieties pure and up to the old high level of quality. No matter how careful and expert the Sea Island cotton planter might be, he labored under a serious handicap on account of the nearness on all sides to Upland short staple. The result has been, as was to be expected, a general deterioration in the quality, through hybridization, even in the most favored section of the Sea Island producing area.

The refusal of the Carolina planters to sell their seed to Georgia and Florida growers has likewise resulted in a general deterioration in the quality of the Sea Island cotton grown in those States, which is, in reality, 90 to 95 per cent of the Sea Island crop of the United States. It has been the custom for years for the farmers of this section to renew at least once in three years their planting seed with fresh stock from Carolina. They seemingly did not rely on a seed selection from their own fields to keep up or to improve the quality of their cotton, and it is even now commonly believed that "Sea Island runs out when planted in the interior or away from the islands of Carolina." There can be no question about the deterioration of Sea Island cotton when left alone under usual farm conditions or when no seed selections are made; but this deterioration is just about as marked on the islands of South Carolina when seed selection is neglected as it is in Georgia or Florida. Soil and climate, of course, influence the kind and amount of lint, but it seems that the chief element in determining the character of the product is the kind of seed planted.[1] The great difference in status between the Carolina planters on the one hand and those of Georgia and Florida on the other is primarily due to the fact that the former have practiced intelligent seed selection for many years, whereas the latter have been content to buy the best planting seed that was obtainable. About four or five years ago, when the Georgia and Florida growers found that they could no longer obtain fresh seed from Carolina a few of them began to make their own seed selections, with very gratifying results, as is shown by the fact that in 1912 one Florida farmer sold his cotton at 47 cents per pound, which surpasses the price paid for some of the extra fancy cottons marketed at Charleston.

But the great mass of Georgia and Florida farmers continued to plant such seed as they had or else the seed which they bought was of inferior quality, and the result has been a gradual reduction in the length, uniformity, and strength of the staple. Climatic conditions during the growing season of 1912 were adverse, and the quality of the cotton was still further lowered. To the New England spinner these are altogether undesirable qualities in cotton. They have meant to him a depreciated value for the home product and, as has been already shown, have rendered the introduction and substitution of Sakellaridis a matter easily accomplished.

(4) *Change in styles and enforced economy of production.*—"Troubles never come singly," and certainly this was true with the Sea Island trade during the year 1912–13. Aside from the troubles already enumerated, but possibly growing out of unsettled business conditions, there was another the influence of which it is hard to overestimate. This was the question of style, coupled with that of economy.

[1] Cook, O. F. The Relation of Cotton Buying to Cotton Growing, U. S. Department of Agriculture, Bulletin 60, p. 12.

Manufacturers reported that the style for women's dress goods had changed from soft, smooth, lustrous cloths, composed of fine yarns and of high counts per inch of both warp and woof, to coarser, rougher effects with fewer threads per inch in the woven fabric. On account of the change of style in women's wear, shirt-waist and petticoat makers had been almost driven out of business and no longer remained important factors as consumers of fine goods.

Such changes in style are of course reflected in the kind of cotton purchased and, as might be expected, the cheapest quality that will answer the purpose is generally bought. The result has been a gradual scaling down in the length of staple being used in the fine goods trade. The longest and finest cottons have felt the effect of this tendency most keenly and, compared with former standards of price, have been sold at the greatest sacrifice.

Closely associated with style is the insistent demand of those who place orders with mills for cloth that the price must be at the lowest possible quotation. In the sale of many lines of goods manufacturers reported that the price is the sole consideration, and the mill quoting the lowest price receives the contract regardless of the quality of its goods. As competition had been keen, mills were forced to accept these low-priced orders and had then striven to cheapen their product in order to make a living profit. The chief means of cheapening the cost of manufacture are the use of either cheaper raw stock or coarser yarns, or both of these ways combined. In many instances both of these remedies have been applied in the recent past, resulting in a coarser, rougher, and more porous style of goods. In a way this cheapening of the cost of production resulted in or helped toward the change of styles, as previously noted, as the arbiters of style are dependent upon goods they find at hand in sufficient quantities to give a ready supply of cloths for their requirements.

Another factor to be reckoned with in the cheapening of the cost of production is improved cotton-mill machinery. With the improvements of recent years, especially since the introduction of combers that can successfully comb even Upland cottons, manufacturers can use shorter staples in their product and still have it look sufficiently attractive to be accepted by the average purchaser. The large use of the shorter staples, especially of $1\frac{1}{16}$ and $1\frac{1}{8}$ inch cottons, for combing has correspondingly lessened the demand for the longer varieties, $1\frac{3}{16}$-inch and longer, and has been partly responsible for the lower prices at which the extra staple cottons have sold.

TIRE CLOTHS AN IMPORTANT EXAMPLE.

In the manufacture of automobile tire cloths the tendency to reduce the cost of production has been especially noticeable. Only a few years ago the best grades of Sea Island cotton were considered none too good for the purpose. Prices and quality were maintained, and the tires were sold under a guaranty as to lasting qualities. Then came competition and a cheapened product. With retail prices for tires cut almost in half, the quality of the cloth used in making them has in most cases deteriorated, and the wearing qualities of the tires are frequently not guaranteed. It was reported as quite common in the manufacture of tire cloths for some mills to use the lowest grades of Sea Island or brown Egyptian. Upland long-staple and even $1\frac{1}{16}$-inch cotton were also being used to a degree for this purpose, and in one instance the substitution of comber waste from Sea Island cotton was reported. Sakellaridis and good quality Sea Island are still used to a limited extent in the manufacture of tire fabrics, but the bulk of this product is from the lower grades of the long staples, especially Egyptian.

This shifting of the tire-cloth trade largely to other cottons has almost closed the largest outlet for Sea Island consumption and is a serious menace to the very existence of the Sea Island industry. However, the final word has not yet been said in the tire-cloth business, and it is still possible that the wearing qualities of tires constructed from low grades of cotton will prove unsatisfactory to their users and that there will be a return to the old standard of quality in tires. Should such a demand spring up, it would probably mean a return to the more elastic and more pliable cloths made of high-grade Sea Island cotton formerly used in the manufacture of tire fabrics.

Briefly summarized, the market situation for the year 1912–13 was extraordinary. The next to the smallest crop for the past 15 years did not go into consumption, although the price was 1 cent per pound lower than that of the very large crop of the year before. Considering the size of the crop and the cost of production, the price was certainly low enough to warrant a sale, but Egyptian and Upland long-staple cottons acted as a substitute to such an extent that a very limited demand existed all the year for Sea Island. It is true that the quality of Sea Island has deteriorated within recent years, but possibly undue emphasis is laid on this derioration and not enough stress is put upon the many excellent qualities still to be found in Sea Island. Market conditions were affected by tariff changes and by changes in the style in women's wear and by changes in the fine-goods trade, and in all of these regards Sea Island cotton was the chief sufferer.

CONDITIONS AMONG PRODUCERS.

Turning from the unusual market situation which existed during the year 1912–13 in the Sea Island trade, it is necessary to consider some of the economic conditions and practices of those engaged in growing and handling this cotton. Here a distinction must be made between the "island," or South Carolina, planters and those in Georgia and Florida. Conditions in these two sections are so dissimilar that they must be dealt with separately.

CAROLINA CONDITIONS.

To understand the present situation among the Carolina Sea Island farmers, it is well to start with them in the days of their prosperity before the Civil War. Then they owned slaves and grew a fine grade of cotton, for which there was a ready sale generally at remunerative prices. They were prosperous and independent and as a rule shipped their cotton to factors in Charleston, who sold it on commission and paid the proceeds over to the farmer, or acted in the capacity of a bank for him and paid his checks when presented. After the war the negroes did not desert the plantations, but as a rule continued to work on the farms, and many are still working there, on the "task" system of slavery days. In financing their business after the Civil War the planters naturally turned to their old friends, the factors, who continued to advance them on open account the money and supplies necessary to make the crop.

To make a long story short, the Civil War was only an interruption in the island farmer's business. He continued to raise cotton with free labor instead of slave, but otherwise there were but slight changes.

During the years from 1865 to 1880 the prices for Carolina cotton were profitable, and South Carolina raised more than one-third of the total Sea Island crop. Its average production was somewhat less than that of Florida, but was far in excess of that of Georgia. This lead over Georgia was maintained until 1889. During these years the importations of Egyptian cotton were almost negligible, and American markets set the price for extra long-staple cotton.

As long as Charleston and Savannah continued to be the chief markets for extra staple cotton, prices remained reasonably satisfactory to the farmers. But with the rapid increase in the Georgia crop and with the great increase in the quantity of long staple grown in Egypt, these cities lost their prestige as long-staple markets and no longer fixed the price for this kind of cotton. With a change in buying methods, accompanied by the rise of interior markets for Sea Island, the price began to fluctuate between wide limits, but as a rule it has been much below the farmer's idea of value. This decline in price at Charleston did not bring about better methods of farming or any visible cheapening of production, but, on the contrary, the cost of production has constantly tended upward over the Sea Island area, as it has done for other commodities over the rest of the Union, until now the cost of growing Sea Island is fully 50 per cent higher than it was in 1896. The increased cost and lower selling prices have resulted in most cases in the farmers becoming involved in debt to the factors. Indeed, it is commonly reported that fully 80 per cent of the Carolina Sea Island crop is now raised on money advanced by factors, and in many instances in the past three years each succeeding crop, instead of reducing, has added to the farmer's debt. At current prices, the crop of 1913 was probably no exception to the rule, and left the producers poorer for having grown it.

THE SYSTEM OF MARKETING AT CHARLESTON.

The structure of the market system at Charleston is the same now that it has been for many years, and is similar to that formerly found at most of the other leading cotton markets. It consists of cotton buyers, factors or commission merchants, and warehousemen. The buyer at Charleston does not buy from the farmer, but only from the factor. In theory the factor acts as the selling agent for the farmer and receives a commission on sales. He never sells directly to the mills, but only to cotton buyers. But, in fact, the chief business of the factor is to advance money and supplies to farmers to enable them to make their crops and to collect these accounts when due. He is the money lender and is indispensable when the farmer is in debt or has insufficient capital for the year's needs. The number of acres planted in cotton by a man measures in a rough way the amount of the advances a factor is willing to make to him on his crop, and this fact accounts for the persistence of many in growing cotton under present low prices. Warehousemen simply receive a storage fee and are not concerned in the actual buying or selling of cotton. The system is good in theory, and was formerly much more general, but its inflexibility is regrettable, and in many cities outside of the Sea Island section this has led to great changes in practice or to the entire abandonment of the system.

There are some unfortunate conditions and practices existing in and around Charleston which are detrimental to the Sea Island trade. These have the sanction of precedent or custom and are therefore hard to change or eradicate.

CENTRALIZATION OF MARKET CONTROL AT CHARLESTON.

Perhaps one of the most notable of the local conditions is the fact that a single firm of cotton buyers usually purchases over three-fourths of the Carolina crop. Four firms of factors make practically all of the advances toward raising the crop. The firm of buyers and all four of the factors do their banking with the same institution. The cotton-buying firm is represented on the directorate of the bank. The potential power of a firm of cotton buyers in such a position is, of course, great; and it matters not how square the relation between the cotton buyer and the bank is or may have been, there are always many who will suspect that the firm's connection with the bank is being used to a selfish end.

Under ordinary conditions in the cotton trade, farmers would be in a position to meet such a situation by offering their cotton through other brokers or to other cotton buyers. But in Charleston this is not an easy matter, as they deal in a specialized commodity which is taken chiefly by the export trade. Their product goes largely to the spinners of Europe, who are thoroughly organized; and when cotton is offered spinners direct they have replied, "Consult our agent in Charleston; he represents us." To ship Charleston cotton to other of the Sea Island markets would mean placing the "island" quality on a level with Georgias and Floridas and would result in a loss in price of 4 or 5 cents a pound on the basis of Charleston sales. Possibly the only feasible relief would be direct consignments of cotton which is free from debt to brokers in Liverpool. Such action might bring reasonable returns for the extra trouble, and at any rate would prevent a farmer from feeling that he was being imposed upon by a combination of buyer, banker, and factor.

CULTURAL METHODS EXPENSIVE.

The task system which has been the custom so long seems to be, as administered now, an unsatisfactory way of getting a day's work for a day's pay. Planters have asserted on more than one occasion that a laborer could finish his allotted task by 9 or 10 o'clock in the morning and was then idle for the rest of the day. Granting that work was commenced at 4 a. m., only six hours at the longest have elapsed before quitting time. Such a period is much shorter than for farm labor in other sections of the cotton belt and is inadequate to maintain the farm in a state of prosperity.

Another economic question is the excessive use of the hoe in making crops on the islands. Hand labor is expensive at best, and it would seem doubly so under the task system, resulting in excessive cost in producing cotton. This result is clearly shown in both the statements as to the cost of growing cotton by the pound and by the acre. Bearing on the same point, it may be said that in Georgia and Florida, where all cultivation except two hoeings is done with the plow, the cost of growing cotton is about two-thirds as great as it is on the islands where hand labor is so largely used. It is true that conditions on the islands are different from those in other parts of the Sea Island area, but it seems that it is certainly worth while to make a trial of substituting horsepower for human power in the growing of cotton.

TOO MANY KINDS OF COTTON.

The diversity of kinds of staples and differences in length seem detrimental to the best interests of the island farmers, yet such conditions have perhaps always existed on the islands, or at least since the special varieties of seed were propagated years ago by intelligent selection. There can be no objection to a few planters growing the extra-stapled Sea Island cottons if they choose to do so, but it would not be advisable to increase the production of these extra staples under the present conditions. If all the farmers of any island would organize for the purpose of growing one variety on a cooperative community basis [1] and then keep their planting seed pure and the variety true to type, they would produce a product much better suited to the needs of a mill. Manufacturers could then rely on a supply of uniform quality and length and in sufficient quantities to make it worth while to turn their attention to it. To make such a scheme feasible it is necessary that the farmer having the most desirable cotton sell his seed to his neighbors until everyone is supplied.

Perhaps the most desirable length for Carolina growers to select is about 1⅞ inches, as such a length would remove the islands from direct competition with 1⅝-inch Georgias and Floridas. However, no exact information along this line has been obtainable, as the Carolina Sea Island is practically all exported, and this investigation has not extended to foreign mills and their requirements in cotton.

PROSPECTS AND ALTERNATIVE CROPS.

There are still good varieties of planting seed among the islands, there are expert cotton breeders, there are good judges of the length and fineness of lint, and there are many good farmers who, after a selection has been made, can grow successfully the selected variety. It seems that a trial along the line of uniform quality is worth while and is practically the only remedy that has suggested itself during the study of the Sea Island situation which holds out a hope for a successful continuation of production for this important crop.

In this connection, it is well to bear in mind that no new information has been gained by this investigation as to the probable price at which Sea Island will sell in the future. During August, 1913, the demand was dull and prices were at or under the cost of production. Styles must change or business revive before any great advance in price can reasonably be expected. And in the meantime the Sea Island farmers must live. They have "a heritage from their fathers which they are loath to relinquish," but it seems the part of expediency that they plant a large portion of their farms in food crops, set aside pasture lands, and pay more attention to beef cattle, hogs, and dairying. Truck farming, if proper shipping facilities can be arranged, would doubtless pay well. And while these other lines of agriculture are being tried out, a small amount of good land should be planted in an approved variety of Sea Island in order to keep pure seed for another crop in case the price again reaches a level

[1] Cook, O. F. Cotton Improvement on a Community Basis, Yearbook, U. S. Department of Agriculture, 1911. Brand, C. J. Improved Methods of Handling and Marketing Cotton, Yearbook, U. S. Department of Agriculture, 1912.

where it is profitable to grow Sea Island in its native home. But until that time does arrive, it is safest for the Carolina Sea Island planters to rely upon home-raised foodstuffs and necessities.

THE APPROACH OF THE BOLL WEEVIL.

The prospect for a continuance of Sea Island cotton as the money crop, not only of the islands but of portions of the mainland of South Carolina, and of Georgia and Florida as well, is rendered even more uncertain by the approach of the boll weevil. At its present rate of progress this pest will overrun the entire Sea Island area in from five to eight years. Those best posted on the nature and habits of this pest are agreed in saying that it may put an end to the profitable production of Sea Island cotton. Over this entire area the winters are especially mild, the atmosphere is humid, and the hibernating quarters abundant, all factors tending to increase the number of weevils. As Sea Island cotton requires a long growing season and matures late in the fall, it will be especially liable to damage from the ravages of this insect. It is none too early for the farmers, especially on the southwestern border of the belt, to begin looking for substitute crops for Sea Island.

CONDITIONS IN GEORGIA AND FLORIDA.

A study of the Sea Island situation in Georgia and Florida develops the fact that conditions are very similar in these two States, and they may therefore be considered together. Georgia perhaps grows its Sea Island somewhat more cheaply than Florida does, but the difference is so slight as to be negligible.

Florida was for many years the leading State in the number of bales produced, but since 1890 Georgia has taken the lead in production and now largely exceeds Florida and South Carolina combined.

In all three States the crops are made chiefly by negro labor, but in Bulloch County, Ga., especially, and to a less extent all over the Georgia area, white labor is largely used. Here farmers owning 1,000 acres or more go to the fields along with their wage hands and do the same work that they expect their employees to do, and see to it that they get the work for which they pay. About two thirds of the cultivated land is planted in cotton, the other third being devoted largely to corn, but some truck crops, especially watermelons, are grown. The farmers have corn and home-raised pork to sell and are self-confident and reasonably prosperous. They think that they can make a living out of Sea Island at 20 cents per pound, but that there would be no profit to them at such a price, and that it would be preferable to grow Upland cotton at 10 cents per pound rather than Sea Island at 20 cents.

UPLAND CROWDING OUT SEA ISLAND COTTON.

In most of the Georgia and in much of the Florida Sea Island area either kind grows well, but Upland is encroaching on Sea Island in every county in which both are being grown. The reasons usually given for this preference for Upland are that its yield is greater, that it is less easily ruined by storms, that it is much easier to pick and to gin, that there is always a ready market for it, that it is less exhaustive to land, and that upon the whole it is just about as profitable as Sea Island.

In both Georgia and Florida the Sea Island crop is made with the strictest economy in human labor, and, indeed, in some parts of Florida economy in labor is carried to the point of neglect. It seems that if crops there were worked better and fertilized more intelligently in some localities the yield would be so much higher that the costs of production per pound would be reduced. But in both States handwork such as found in South Carolina is unknown. Cotton is thinned with a hoe, or "chopped to a stand," and generally hoed once thereafter, but all the rest of the cultivation is with plows or cultivators, resulting in a decided cheapening of the cost of production.

INTERIOR MARKETING.

The system of business for the interior market is different from that prevailing at Charleston, or at Savannah, which resembles Charleston in organization. The interior markets are of comparatively recent growth and have few rules or traditions which must be complied with. In most of these markets some enterprising firm operates a modern gin. The firm buys the cotton in the seed wherever it is offered for sale and ships it to its ginhouse to be ginned and baled. It is then offered direct to spinners by the ginning company. In case the ginner receives orders for cotton he does not have, he either buys it from some farmer who owns a gin or on the Savannah market.

GOOD WORK OF GINNING COMPANIES.

The ginning companies have been of great assistance to farmers in getting new and improved seed for planting purposes. It has already been explained how difficult it has been to get new seed from the Carolina islands during the past few years, but the ginners of Georgia and Florida have secured the best seed obtainable under the circumstances and have distributed it among their farmer patrons. They have shown the proper appreciation of their situation and have endeavored to remedy it. It seems probable that they will soon find access to an ample supply of Carolina planting seed that will produce at least a $1\frac{5}{8}$-inch staple of uniform length and of good strength.

MIXING SEED COTTON A PERNICIOUS PRACTICE.

There is a practice quite common in these two States, and perhaps in South Carolina also, of selling cotton in the seed in small quantities, even in basketfuls. These small lots are supposed to be graded while in the seed-cotton condition and then each grade or lot kept separate until it is ginned. If grading is ever attempted it amounts to little, and it has become the custom to put all the lots in one pile and to gin and bale it, indiscriminately, all at the same time. The resulting staple is mixed and far from desirable to a spinner, but, strange to say, such lots of cotton are frequently accepted by mills at a price equal to or but slightly less than a well-selected and carefully handled cotton could be bought for. Such a statement sounds incredible, but it shows how imperfect are the methods by which many mills determine the character of the cotton which they purchase. It is a confusing situation to both planters and factors and has unquestionably encouraged careless methods of handling cotton.

CONCLUSION.

In conclusion it may be said that it is certainly desirable to the farmer now growing Sea Island that it should continue to be one of his chief money crops, but only on the condition that it be a profitable one. It is likewise desirable to the American spinner that he should have a double source of supply for his raw material and that he should not be dependent on Egypt for all cottons of extra-long staple. This applies equally to foreign spinners who have not been lacking in appreciation of Sea Island extra staples. Thus, their interests being identical in regard to the desirability of continuing the production of Sea Island, it seems worth while to make an effort to reconcile differences and to reach a working agreement on a "live and let live" basis. In furtherance of this end it might be advisable for the farmers' organizations and spinners' association to each appoint a small committee to meet in conference at an early date and have a full and free exchange of views and each learn more of the conditions and needs of the other. Doubtless a better understanding could be reached, which would lead to mutual concessions and the forgetting of the deadlock of 1912–13, and the business of both planter and spinner might be greatly benefited by such an interchange of ideas.

APPENDIX.

TABLE I.—*Crops and prices of Sea Island cotton, 1865 to 1913, inclusive.*[1]

[These are average prices first cost Savannah for the average grade of Georgia and Florida cotton.]

Season.	Crop.					Price per pound.	Foreign exports.			American consumption.	Stock Aug. 31.
	Florida.	Georgia.	South Carolina.	Texas, etc.	Total.		Great Britain.	Continent.	Total exports.		
	Bales.	*Bales.*	*Bales.*	*Bales.*	*Bales.*	*Cents.*	*Bales.*	*Bales.*	*Bales.*	*Bales.*	*Bales.*
1912-13	20,147	39,557	8,376	......	68,080	20	10,914	5,206	16,120	41,899	15,639
1911-12	42,484	75,138	5,122	......	122,744	21	13,685	6,615	20,300	102,846	5,533
1910-11	28,849	45,646	13,416	......	87,911	28	13,346	5,808	19,154	64,928	5,738
1909-10	28,711	53,124	14,821	......	96,656	27	20,243	5,145	25,388	72,417	1,887
1908-9	39,045	46,983	15,392	......	101,420	18	15,631	7,241	22,872	79,493	2,340
1907-8	27,993	44,694	12,691	......	85,378	21	19,466	10,718	30,184	52,680	3,223
1906-7	20,170	29,413	8,037	......	57,620	30	13,501	5,926	19,427	38,681	709
1905-6	42,437	67,215	13,712	......	123,364	18	24,897	9,206	34,103	90,484	1,197
1904-5	32,026	58,471	12,171	......	102,668	19	23,351	8,459	31,810	72,153	2,420
1903-4	28,005	39,345	9,359	......	76,709	23	24,188	7,132	31,320	43,558	3,715
1902-3	27,686	62,451	12,497	......	102,634	19	44,354	9,728	54,082	50,524	1,904
1901-2	21,323	48,538	8,760	......	78,621	20	25,423	6,450	31,873	43,650	3,876
1900-1	24,793	52,953	8,369	......	86,115	21	26,453	5,535	31,988	55,422	778
1899-1900	29,376	60,369	7,810	......	97,555	15	38,279	8,007	46,286	49,543	2,073
1898-99	21,275	40,306	5,623	......	67,204	11	26,451	9,015	35,466	38,654	347
1897-98	25,468	41,440	10,211	......	76,119	12	33,303	8,827	42,130	34,140	7,263
1896-97	25,927	64,906	11,039	1,644	103,516	14	47,758	10,673	58,431	40,670	7,414
1895-96	21,664	64,522	10,010	991	93,187	16	42,391	7,672	50,063	40,530	2,999
1894-95	15,176	53,716	5,913	34	74,839	15	35,091	5,650	40,741	34,981	405
1893-94	19,107	39,367	2,578	......	61,052	18	32,647	4,686	37,333	24,345	1,288
1892-93	9,685	28,324	7,413	......	45,422	21	20,647	1,901	22,568	22,911	1,914
1891-92	20,628	27,100	11,443	......	59,171	16	24,915	2,653	27,568	32,093	1,951
1890-91	25,320	26,531	16,267	......	68,118	19	34,293	4,823	39,116	26,651	2,441
1889-90	25,111	12,431	9,299	......	46,841	24	25,984	2,294	28,278	19,142	90
1888-89	26,909	7,462	9,552	......	43,903	22	21,245	1,800	23,045	20,336	669
1887-88	24,753	6,254	8,564	......	39,571	21	18,665	1,915	20,580	19,685	147
1886-87	30,991	6,411	7,735	......	45,137	18	25,216	1,435	26,651	20,516	841
1885-86	24,272	6,390	7,010	......	37,672	23	14,748	1,680	16,428	19,983	2,871
1884-85	24,987	3,075	12,863	......	40,925	26	18,422	3,143	21,565	17,965	1,610
1883-84	14,073	2,956	8,415	......	25,444	32	12,166	1,413	13,579	11,674	215
1882-83	18,054	3,126	15,715	29	36,924	26	21,565	1,892	23,457	13,573	24
1881-82	21,842	6,049	10,642	19	38,552	24	22,303	2,453	24,756	14,762	130
1880-81	18,410	3,179	14,845	8	36,442	28	20,259	4,136	21,395	11,270	1,096
1879-80	13,318	3,420	9,966	......	26,704	28	13,729	3,294	17,023	9,389	319
1865-1879	131,651	61,703	102,984	3,974	300,312	......	240,554	18,247	258,801	41,979	......

[1] The Office of Markets is indebted to Messrs. Gordon & Co., of Savannah, Ga., for Tables I and II. Table I is presented in preference to the table by the Census Bureau, with which it is in substantial agreement, because it covers a much longer period of time than the census figures do. Table II gives greater detail than does any corresponding table issued by the Census Bureau.

TABLE II.—*Sea Island cotton statement from Sept. 1, 1912, to Aug. 30, 1913.*[1]

Receipts.	Crop, 1912–13.	Crop, 1911–12.
	Bales.	*Bales.*
Stock at Savannah and Charleston Sept. 1, 1912	5,533	5,738
Received at Savannah, net	38,533	62,926
Received at Charleston	8,375	5,122
Received at Jacksonville	11,780	47,755
Received at Brunswick	1,956	899
Received at southern mills from interior, taken from advance sheets Cotton Record	7,436	6,042
Total	68,080	122,744
	73,613	128,482

Shipments.	To domestic mills.	To Great Britain.	To Continent.	Total.
	Bales.	*Bales.*	*Bales.*	*Bales.*
From Savannah	18,886	8,977	2,076	29,939
From Charleston	1,841	1,937	3,130	6,908
From Jacksonville	11,780			11,780
From Brunswick	1,956			1,956
From interior	7,436			7,436
Total	41,899	10,914	5,206	58,019
Same time last year	102,846	13,685	6,615	123,146
Decrease	60,947	2,771	1,409	65,127

Stocks, August 30.	1913	1912
	Bales.	*Bales.*
In Savannah	13,717	5,078
In Charleston	1,922	455
Total	15,639	5,533

[1] See footnote to Table I.

TABLE III.—*Estimated average grade of Upland cotton, and average price of Upland, Sea Island, and Egyptian cotton.*[1]

Growth year.	Estimated average grade of Upland cotton.	Average price of cotton fiber per pound (cents).				
		Upland.	Sea Island.			Egyptian.
			Florida.	Georgia.	South Carolina.	
1912	Middling to strict middling	12.05	19.50	19.50	25.00	19.76
1911	Strict low middling to middling	9.69	20.41	20.41	23.73	18.75
1910	Strict middling	14.69	27.36	27.36	35.62	22.25
1909	do	14.29	27.10	27.10	32.85	20.50
1908	do	9.24	17.92	17.92	23.39	17.25
1907	Middling	11.46	24.27	24.27	35.59	21.00
1906	Strict low middling	10.01	28.65	28.65	36.70	20.00
1905	Fully middling	10.94	17.50	17.50	26.38	19.00
1904	Strict middling	8.66	19.50	19.00	27.12	15.00
1903	do	12.16	23.60	21.00	28.40	17.75
1902	Strict low middling	8.20	20.00	17.00	25.00	15.50

[1] U. S. Department of Commerce, Bureau of the Census, Bulletin 116, p. 19.

TABLE IV.—*Net imports of raw cotton, by countries from which imported, for the year ending Aug. 31, for specified years: 1895 to 1913.*[1]

Year.	Net imports of raw cotton (equivalent 500-pound bales).				
	Total.	Imported from—			
		Egypt.	United Kingdom	Peru.	All other countries.
1913	225,460	182,238	8,071	10,300	24,851
1912	229,268	175,835	27,049	9,201	17,183
1911	231,191	183,786	9,717	10,221	27,467
1910	151,395	102,217	19,435	12,076	17,667
1909	165,451	129,985	15,722	13,508	6,236
1908	140,869	120,187	13,741	5,586	1,355
1907	202,733	169,731	22,493	8,564	1,945
1906	133,464	103,669	20,176	7,440	2,179
1905	130,182	108,283	14,723	5,941	1,235
1900	134,778	106,166	21,810	5,116	1,686
1895	99,399	59,864	36,213	2,335	987

[1] U. S. Department of Commerce, Bureau of the Census, Bulletin 117, p. 9.

TABLE V.—*Quantity of kinds of raw cotton consumed and of stocks held in manufacturing establishments: 1911, 1912, and 1913.*[1]

[Quantities are given in running bales, except that round bales are counted as half bales and foreign cotton in equivalent 500-pound bales. Linters are included.]

Kind and locality.	Raw cotton consumed during year ending Aug. 31 (bales).			Stocks held in manufacturing establishments on Aug. 31 (bales).		
	1913	1912	1911	1913	1912	1911
United States	5,786,330	5,367,583	4,704,978	778,158	870,646	542,191
Domestic:						
Upland	5,195,614	4,826,827	4,258,750	619,200	709,495	398,065
Sea Island	54,778	94,856	64,237	18,525	23,753	19,280
Linters	303,009	238,237	206,561	60,454	52,622	43,422
Foreign:						
Egyptian	201,269	180,465	147,192	70,859	77,029	70,678
Peruvian	10,341	8,539	8,903	1,044	1,482	1,456
Indian	2,412	6,842	9,793	673	3,806	3,909
Other	18,907	11,817	9,542	7,403	2,459	5,381
Cotton-growing States	2,960,518	2,712,223	2,328,487	234,509	241,611	101,114
Domestic:						
Upland	2,834,732	2,609,369	2,230,225	210,883	224,730	83,103
Sea Island	12,696	11,112	7,987	2,664	1,916	655
Linters	98,775	76,345	79,352	15,325	11,508	11,980
Foreign:						
Egyptian	10,051	12,557	6,578	4,053	2,767	4,644
Peruvian	6			4		
Indian	475	285	2,092	353	4	222
Other	3,783	2,555	2,253	1,227	686	510
All other States	2,825,812	2,655,360	2,376,491	543,649	629,035	441,077
Domestic:						
Upland	2,360,882	2,217,458	2,028,525	408,317	484,765	314,962
Sea Island	42,082	83,744	56,250	15,861	21,837	18,625
Linters	204,234	161,892	127,209	45,129	41,114	31,442
Foreign:						
Egyptian	191,218	167,908	140,614	66,806	74,262	66,034
Peruvian	10,335	8,539	8,903	1,040	1,482	1,456
Indian	1,937	6,557	7,701	320	3,802	3,687
Other	15,124	9,262	7,289	6,176	1,773	4,871

[1] U. S. Department of Commerce, Bureau of the Census, Bulletin 117, p. 14.

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THE EFFECT OF THE CATTLE TICK UPON THE MILK PRODUCTION OF DAIRY COWS.

By T. E. Woodward and W. F. Turner, *Dairy Division*, and Cooper Curtice, *Zoological Division.*

INTRODUCTION.

The common cattle tick, *Margaropus annulatus*, infests the cattle throughout the greater part of Florida, Georgia, Alabama, Louisiana, and Arkansas, large portions of Texas, Oklahoma, Mississippi, South and North Carolina, and small areas in Virginia and California. On account of the enormous losses occasioned by the parasite, it has been necessary to quarantine the area infested, so that cattle outside of this area may be protected. Ever since 1906 tick eradication in the infested area has been actively pushed by Federal and State governments, cooperating with citizens of tick-infested regions, to destroy the pest. While the majority of farmers admit some loss, few are aware of its extent, hence the experiments reported in this bulletin were undertaken to bring out the facts, particularly in relation to the effect of the tick on dairy cows.

The cattle tick is an almost exclusive parasite of cattle. While the ticks may mature on horses, mules, and possibly deer and sheep, their control on these animals has proved to be comparatively easy. All ticks come from eggs laid by the adult female ticks. An engorged female tick dropping from a cow completes oviposition in from five days to a week; the eggs hatch as a rule in about 21 days in ordinary summer weather; the issuing seed ticks crawl upon the grass and await the coming of cattle upon which they crawl when opportunity offers; they then reach maturity in from 21 to 25 days.

While maturing each tick abstracts a definite amount of blood from an animal, and to that degree injures it. The quantity of blood abstracted is many times the weight of the ticks when grown, for these represent only that part of the solids and fluids of the blood which may be converted into the tissues of the tick, the remaining solids and fluids being rejected. The amount of blood taken by a single tick may be relatively small, but the total amount drawn by thousands of ticks on one cow can not fail to be injurious. If each tick represents but a dram, or a teaspoonful, of blood, a few over 1,000 would represent 8 pounds of blood. It is possible that each tick absorbs more than a dram of blood.

But the greatest disturbance created by the tick seems to be, not in the amount of blood abstracted, but in the fact that it is the carrier of the germ of Texas fever which it transmits to cattle.[1] When cattle that have never become accustomed to ticks are infested they become very sick and usually die. This may occur anywhere, either within or without the tick-infested region. Cattle that survive the ticks usually remain immune to their worst effects afterward. However, as time passes the important fact that no cattle in the quarantined area of the South are ever safe from the effects of Texas fever, either in its acute or chronic form, becomes more and more impressed on those who have to study the affected cattle.

PLAN OF THE EXPERIMENTAL WORK.

As the dairy industry is becoming an important branch of southern agriculture it was thought desirable to ascertain the effect of the tick on the milk production and body weights of dairy cows. Twenty grade Jersey cows [2] of about average dairy quality were selected in the early part of their lactation periods. They were in fair condition of flesh at the beginning, and all had been tick infested at some time. The animals being immune to ordinary attacks of tick fever, the results should be applicable to the average dairy herd in the tick-infested areas. These cows were divided into two groups of 10 animals each, the two groups being balanced as nearly as possible in regard to milk and butter-fat production, condition of flesh, and size. One group was freed from ticks by spraying with "tick dip B," an arsenical solution used by the Bureau of Animal Industry in the tick-eradication work. Data were taken on only nine cows of this group, as one cow received an injury to her udder which stopped her milk flow early in the test. The other group was kept tick-infested by applying seed ticks at regular intervals. The degree of infestation varied with different animals and with the entire group at different times during the course of the experiment.

The experiment began May 21, 1913, and lasted during a period of 140 days. The milk of each cow was weighed and a sample taken at every milking for a composite fat test at the end of each 10-day

[1] Further details concerning the life history of the cattle tick and the protozoan causing the fever can be found in Farmers' Bulletin 258.

[2] The cows and the feed lots used in these experiments were provided by the Anthony Farms Co., Anthony, Fla., of which Mr. E. C. Beuchler is manager and vice president.

period. The body weights were taken for 10 consecutive days at the beginning of the work; thence once every 10 days until the last period, when they were taken for 10 consecutive days as at the beginning of the work. The weights were taken at about the same hour and under the same conditions each time, so that the extent of fill, both as regards feed and water, would be similar. The treatment of the two groups in all respects other than ticks was as nearly alike as possible.

FEEDING.

The tick-free group of cattle were fed as much alfalfa hay as they would eat readily, and enough corn chop, wheat bran, and cottonseed meal, mixed in the proportions 4 : 2 : 1, to maintain the body weights. The aim was to give the infested group the same kind and amount of feed, but toward the close of the experimental period these cows failed to consume as much hay as the tick-free cows. In order to make the digestible nutrients consumed practically equal for each group, the grain ration of the infested cows was raised 1 pound for each 2½ pounds of hay refused. Both groups of cows had access to salt and water in unlimited quantities.

THE TICKS.

The seed ticks used to obtain the various degrees of infestation in the cattle were the progeny of mature ticks obtained from several sources. The supply of ticks was secured through the cooperation of Dr. Charles F. Dawson, of the Florida State Board of Health, as the local supply was insufficient. Dr. Dawson's first material was collected from Tallahassee, Kissimee, Dade City, and other places in Florida. A few small lots were received subsequently. The earlier adult ticks were collected between April 13 and April 28. The seed ticks or larvæ from eggs laid by these emerged between May 22 and June 2, following. On June 12 and 14 two other consignments were received. The resulting broods seemed sufficient to insure thorough infestation of the cattle during the first weeks of the experiment.

A second source of seed ticks was the Anthony Farm cattle not under test. This supply, together with that already mentioned, was sufficient to last until the middle of July by applying them but once a week. These two sources of supply proved to be insufficient, and a third lot was obtained from the Zoological Division of the Bureau of Animal Industry. These were mainly a portion of the original collection by Dr. Dawson, which had been sent by him to Washington and intended for another purpose. One flask of specimens labeled as originating in Texas accompanied these. This Washington consignment was applied during July. As fast as the ticks matured on the experimental cattle they were picked off, and the seed ticks derived from them became available about August 1. From that time on there was an abundance of material.

The time of application of the ticks may be roughly divided into two periods, viz, from June 4 to July 28, in which ticks were applied at intervals of seven or eight days, and from August 1 to September 25, in which they were applied on each alternate day with but two exceptions. The effect of weekly applications was to cause the ticks to ripen in groups covering about five days; the alternate day applications caused a more continuous and intense infestation. The exact fluctuations of this were not determined on account of cessation of gathering ticks when sufficient had been obtained to complete the experiment.

Collections of ticks from the experimental cattle were made twice daily during milking time from June 26 to September 4. This was necessary in order to obtain seed ticks for a continuation of the experiment into the fall months. The deleterious effects of the ticks were less than if they had been allowed to mature on the cattle; but in such case future seed ticks would not have been available. Additional effort to acquire material from other sources demonstrated the futility of depending upon outside sources for seed ticks. As the experiment proceeded it became too late to employ other cows for raising ticks, a plan which would be better if the experiment were to be repeated.

The count of the ticks made and given in an appended table does not include all that became attached to the cattle, for some dropped off, some were picked off by chickens, and others were licked off by the cattle themselves. Also many incompletely mature ticks were collected which might have added their share of damage to that already produced. Table 1 contains the number of ticks picked from each cow daily, the dates when they were applied, and their source. The infestation during the earlier period, June 4 to August 5, was practically like a fall infestation in intensity, excepting that the ticks were not maturing equally throughout the week, thus causing milder effects during the time that the ticks matured less rapidly. Infestation on different cows was from slight to gross during the whole experiment. Under farm conditions pasture infestations may occur daily, thus making continuous appearances, such as occurred during only a part of the week in the experiment, and producing consequently more severe injuries. The collecting of ticks was continued until within 30 days of the close of the experiment, when the supply was sufficient to maintain infestation until the completion of the work.

TABLE 1.—*Source of seed ticks placed on cows and number of ticks picked from each cow at stated periods.*

Period.	Source of seed ticks placed on the cows.	Number of ticks picked from—										
		Cow 11.	Cow 12.	Cow 13.	Cow 14.	Cow 15.	Cow 16.	Cow 17.	Cow 18.	Cow 19.	Cow 20.	Total.
1913.												
June 26 to July 1	Florida, except Anthony	1	14	16	3	44	15	6	1	2	5	107
July 2 to July 9	Anthony (few) and other places.	2	181	63	6	256	49	35	3	54	170	819
July 10 to July 19	Anthony and other Florida	0	728	187	40	707	217	104	7	146	370	2,506
July 20 to July 29	Anthony (most) and other places.	2	1,106	414	53	1,475	252	129	3	231	670	4,335
July 30 to Aug. 8	Anthony (few) and other places.	0	355	451	16	1,843	223	85	0	54	699	3,726
Aug. 9 to Aug. 18	Florida (except Anthony) and Washington, D. C.	6	93	119	16	825	158	84	3	68	300	1,672
Aug. 19 to Aug. 28	Anthony, Fla	7	906	872	66	1,184	392	615	6	139	980	5,167
Aug. 29 to Sept. 5	do	8	3,892	2,603	45	8,116	1,594	2,430	8	230	6,467	25,393
Total		26	7,275	4,725	245	14,450	2,900	3,488	31	924	9,661	43,725

NOTE.—No ticks were picked after Sept. 5, as there was then a sufficient supply of mature ticks on hand from which to procure seed ticks for the remainder of the experimental period.

The infestation from August 20 to October 7 was unusually large in those animals which were susceptible to the ticks; in others the infestation was only slight, as throughout the experiment. It may be said, however, concerning the infestation generally that the table does not present a complete picture to the eye, nor do photographs taken on various dates. In the weekly infestation there were three or four broods on the cows at the same time, viz, newly attached seed ticks, week-old, two-weeks old, and, depending on the exact date, maturing ticks. In alternate-day infestation there were 11 broods on at once. On cows which favored their development one could feel by touch the young ticks that were covered by hair. From the beginning difficulty was experienced in gaging the number of young ticks that should have been put on the cows. In the weekly infestation all the available ticks were used. The effects would not have been different had the same numbers been applied at intervals throughout the week. The infestation would have been less visible, however.

Effort was made to apply about the same number each time, but later application gave better results than earlier ones. While the number placed on the animals was purely a matter of judgment, it is probable that the numbers applied from day to day did not vary so much as did the vigor with which the ticks attached themselves to the cattle. After the seed ticks were applied no changes could be made and results alone proved the numbers that remained on the cattle.

The seed ticks were applied by permitting them to crawl on to the cow's hair in various places from the edge of pint fruit jars used in hatching them. Sufficient time was allowed after hatching to permit the seed ticks to harden and become brown. They had been confined in the jars by cotton cloth. This cloth was used later to wipe up the ticks and scatter them over the cattle. In the first period of the experiment the ticks were mainly placed on the backs, bellies, and escutcheons of the cows, but in the second period they were placed more generally over the entire body.

Some of the tick masses became too moist during oviposition and incubation in the wet season, and this caused the masses to adhere and resulted in the death of the larvæ, especially when too many of the adult ticks were put together. Previously many egg masses had been kept too dry, presumably on account of atmospheric conditions and the small number of adults placed in a jar. Later on better conditions were secured by collecting the ticks in paper bags in lots of 200 or 300 and transferring them to the cloth-covered jars when they were nearly hatched.

These methods caused the numbers of seed ticks occurring on the cattle to be purely guesswork. Failure resulted in spite of special efforts to infest those cattle that presented the fewest adult ticks. Such were nearly immune to ticks.

RESULTS OF EXPERIMENTS.

The damage done to the infested cows by the ticks seems to have arisen from two distinct causes; first, a fever incited in some of the cattle at various periods, and, second, loss of blood abstracted by the growing tick.

FEVER CAUSED BY THE TICKS.

The presence of fever on various dates is shown in Table 2, where temperatures of both tick-infested and tick-free cows are shown. No attempt was made to take daily temperatures, as the matter of taking any temperatures at all was an afterthought rather than part of the plan. One set of temperatures was taken at 9 a. m.; all others at 4 p. m. The temperatures of the tick-infested cattle were higher than the checks and nearly always above normal. The temperatures of the tick-free cattle were also often above normal. This may have been due to moist, hot conditions of the atmosphere, since only in exceptional cases were the temperatures abnormal on cool days.

TABLE 2.—*Temperature records of the experimental cows at various periods and average of all readings.*

Cow No.	Degree of tick infestation.	July 27, p. m.	Aug. 2, p. m.	Aug. 6, p. m.	Aug. 14, p. m.	Aug. 19, p. m.	Aug. 27. A. M.	Aug. 27. P. M.	Sept. 1, p. m.
1	Free	102.2	102.2	101.8	103.2	101.8	101.8	101.6	102.6
2	....do	102.2	102.8	101.8	103.6	101.8	101.8	102.3	104.0
3	....do	103.2	102.4	103.6	105.6	102.8	102.6	102.2	104.4
5	....do	102.0	102.4	103.0	103.8	101.8	101.8	101.6	103.0
6	....do	103.2	102.2	102.4	104.8	102.5	101.6	102.2	105.4
7	....do	102.8	102.2	103.4	105.9	103.2	102.2	101.2	105.2
8	....do	102.6	103.0	103.2	104.4	102.2	101.2	102.2	104.6
9	....do	104.4	103.2	102.4	104.7	103.0	101.8	102.6	105.0
10	....do	101.1	103.0	102.6	104.5	102.8	101.2	101.6	103.0
11	Light	103.2	102.8	101.8	103.8	103.2	101.8	102.4	103.6
14	....do	102.8	102.4	101.8	103.0	102.2	101.6	102.8	102.8
18	....do	104.0	102.2	102.4	104.4	103.4	102.4	103.2	104.2
19	....do	103.6	103.0	102.0	104.4	103.0	102.0	102.2	103.8
16	Medium	103.6	103.8	102.4	105.0	103.8	102.2	103.0	104.8
17	....do	102.8	103.0	102.8	103.8	103.6	103.2	105.0	104.2
12	Heavy	104.0	104.0	102.4	104.4	104.0	102.2	103.0	104.2
13	....do	106.8	104.6	103.6	106.8	106.2	104.4	102.8	106.2
15	....do	104.0	103.0	103.2	104.2	103.6	102.2	102.6	105.2
20	....do	103.8	103.4	102.2	104.2	103.6	102.2	102.8	103.8

Cow No.	Degree of tick infestation.	Sept. 2, p. m.	Sept. 3, p. m.	Sept. 4, p. m.	Sept. 5, p. m.	Oct. 1, p. m.	Oct. 2, p. m.	Oct. 3, p. m.	Average.
1	Free	102.4	102.0	102.2	101.8	100.2	104.2	102.4	102.16
2	....do	103.5	103.4	102.0	100.6	102.2	103.2	102.8	102.53
3	....do	104.2	105.2	104.2	101.0	103.0	104.8	103.6	103.52
5	....do	103.0	103.8	102.6	102.4	104.0	104.0	104.0	102.88
6	....do	104.6	104.5	103.6	101.0	103.2	104.2	103.4	103.25
7	....do	104.8	105.8	103.2	101.4	102.6	103.0	103.4	103.35
8	....do	103.6	102.8	103.4	101.0	104.4	104.0	103.6	103.08
9	....do	104.6	104.2	101.8	102.2	103.2	105.2	104.6	103.52
10	....do	103.4	102.6	102.6	102.0	103.2	103.6	102.6	102.65
11	Light	103.6	103.8	104.0	102.2	103.2	103.4	102.2	103.00
14	....do	102.2	102.4	102.8	102.2	102.2	102.2	102.2	102.37
18	....do	102.8	102.8	104.2	102.2	103.8	103.2	103.4	103.24
19	....do	105.4	104.4	104.6	102.6	104.4	104.0	102.7	103.47
16	Medium	105.2	104.6	105.6	102.8	104.8	103.8	103.6	103.93
17	....do	104.2	104.6	104.6	102.8	104.6	103.8	103.2	103.74
12	Heavy	104.2	104.0	104.0	102.6	104.4	104.2	102.4	103.60
13	....do	106.0	105.8	104.0	103.4	105.0	105.2	103.6	104.96
15	....do	104.2	104.5	104.4	102.8	106.2	105.8	105.2	104.07
20	....do	103.8	104.2	104.2	103.2	105.4	104.4	103.2	103.65

Blood taken from cows 12 and 13 and observed to run from the tick wounds of cows 15, 17, and 20 in particular was abnormal in being too thin. The red blood clots formed but a small part of the mass. All these animals, also cow 16, were noticed to be visibly distressed as to feelings and respiration on various occasions. Cow 15 alone showed a slight pendulous swelling under the lower jaw. Cows 11, 14, 18, and 19 were infested with but few large ticks and not many visible small ones. Neither were they apparently ill at any time. To what quality these cattle owed their immunity from ticks is not known. They looked more like Jersey cattle than the other ones infested. In color cow 14 was lemon fawn and cow 19 was light fawn, and the latter's coat was very short and thin. Cow 15, the cow that became most heavily infested, was a large red brindle cow that resembled the Shorthorn or beef type. (Fig. 1.) This cow seemed to resist the effects of the ticks until toward the end of the experiment, but finally failed rapidly in giving milk and died within a week after the close of the experiment.

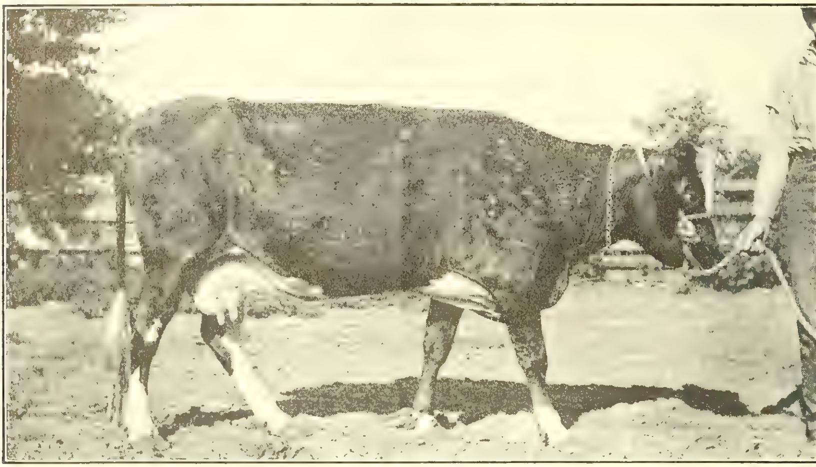

FIG. 1.—Cow No. 15, heavily infested with ticks over the entire body. This was one of the best cows in the group, but she died of tick fever shortly after the close of the experiment. Photo taken Sept. 25, 1913.

Cow 20 was infested almost as heavily as cow 15. She was a large Jersey-like cow of lemon-yellow color. (Fig. 2.) Her milk failed quite early in the experiment. She presented a dejected appearance

FIG. 2.—Cow No. 20, heavily infested on neck and shoulders. Photo taken Sept. 24, 1913.

for some time but later recuperated and gained or held her weight to the end. Externally there seemed to be no reason why ticks developed so much more on her than on cow 14.

Cow 12, a mongrel Jersey with black predominating and white under parts, was the next most infested. (Fig. 3.) She became ill but acquired the habit of licking herself as clean of ticks as she could and of being assisted by other cows. She seemed to recover from her fever and improved somewhat in condition.

Cows 13, 16, and 17 were infested about alike, but Nos. 13 and 17 suffered more from fever than No. 16. There seemed to be no particular difference in the coats of Nos. 13 and 16 sufficient to explain why No. 16 should be less infested. They were red cows of mixed origin and doubtful ancestry. Cow 17 (fig. 4) was a very dark cow with white under parts, having a rather fine Jersey-like head. The sickness reduced her milk flow much more than was the case with No. 13. As a whole, the light fawn-colored cows seemed to resist ticks better than the dark-colored ones.

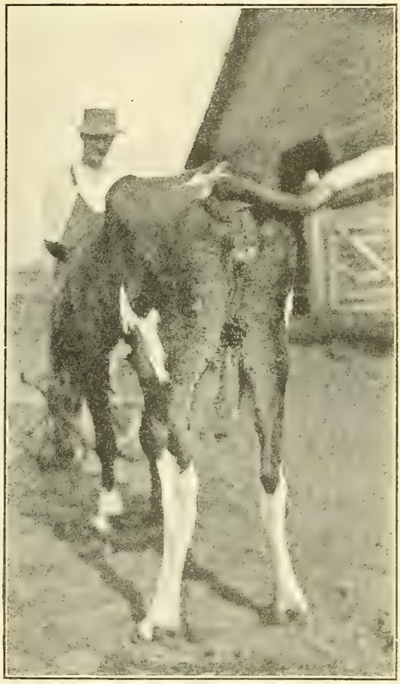

FIG. 3.—Cow No. 12, heavily infested on rear parts. Photo taken July 19, 1913.

The sickness in the cattle was not entirely due to the number of ticks, for cows that had fewer ticks by far than cow 15 were sick much earlier. It has previously been stated that one of the sources of ticks was the Anthony farm. This farm sustains a large dairy, and frequently the herd is replenished with fresh milkers brought from Georgia and the surrounding country. According to the superintendent, many go through acclimatization or Texas fever. It is quite probable that ticks from some of the acclimatized animals furnished the first protozoa (piroplasma) to produce disease in the experimental animals; it may be that afterwards ticks from sick cows in the experiment transferred the disease to other cows. While all these cattle were used to ticks, it is quite evident that they were not thoroughly immune to fresh attacks of disease, whether due to blood-letting or piroplasma parasitism. That immunity is a variable quantity is accepted by many southern cattlemen who have studied and had experience with traded cattle.

The 10 check cattle remained free from ticks through keeping them in a separate pen and stalls; otherwise they were under similar conditions as the infested cattle. Although they were separated from the tick-infested group in the stable by the mangers only, and later turned out into a small field on account of the muddy condition of the barn lot, there was insufficient manifestation of small ticks to show pen and yard infestation. However, it was thought necessary to spray these cattle on occasions because of a few scattered ticks which were presumably carried to them on the rag with which the udders were washed. Spraying was followed for a day or two by a diminished quantity of milk, after which the normal flow reestablished itself. The spray used was arsenical tick dip B, a concentrated solution which when used in prescribed dilution produced a subsequent slight exfoliation of the epidermis.

The deleterious effects of the ticks were not so apparent in the experiment as they would have been had more ticks been developed

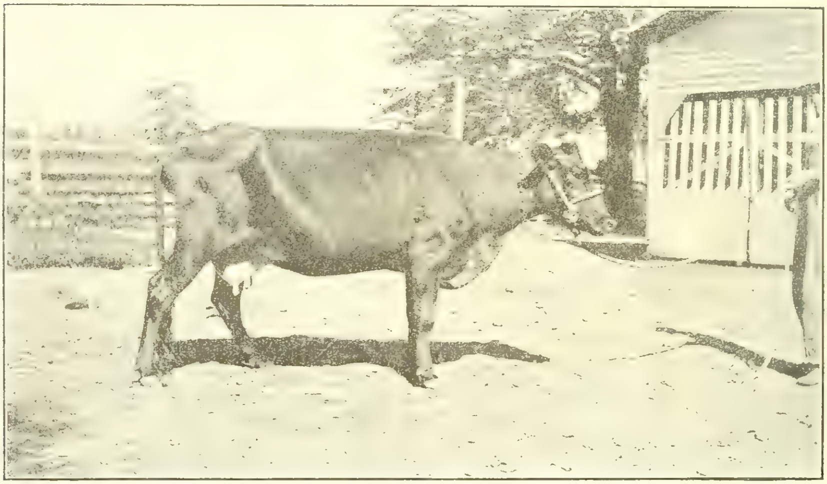

FIG. 4.—Cow No. 17, showing moderate infestation with ticks.

early in the experiment. In that case early losses would have been reflected throughout. It is probable that excessive invasions of ticks on freshening cows in spring reduces their milk flow by fully one-half before the lactation period is ended.

An attempt was made to put on about the same number of seed ticks at each application, so that the number applied from day to day was probably fairly uniform. Seed ticks secured from adult ticks from outside sources seemed to be less vigorous and to have more difficulty in attaching themselves to the cows than those more recently obtained from ticks that had matured on the Anthony cattle, so that fewer of them matured and consequently less damage resulted than when the Anthony ticks were used. This apparently low vitality of the seed ticks obtained from outside sources, together with the light infestation obtained at the early part of the work, delayed any definite results until toward the latter part of the experimental period.

The cows used were so-called immune, yet all the tick-infested group except the four lightly infested ones suffered from attacks of fever at different times during the experimental period. This was not due entirely to the number of ticks maturing upon these animals, for cow 15, which showed the heaviest infestation throughout the entire period, was one of the last to suffer from an attack of fever.

EFFECT OF TICKS ON MILK PRODUCTION AND BODY WEIGHT.

Although each of the cows used in this work had been tick infested at some time, the individual variation in the degree of infestation that could be obtained was so wide that two subgroups were made of four animals each, one of which will be called the lightly infested and the other the heavily infested group. These subgroups show the effect of varying degrees of infestation upon the body weights and milk production of the cows in a manner more marked than when the two entire groups are compared. In the discussion which follows only the summaries of groups are given. Complete data for each cow will be found in the appendix. The average results are shown in Table 3 following, and graphically in the chart, figure 5.

TABLE 3.—*Effect of tick infestation on milk production and body weight of cows.*

Group.	Number of cows.	Milk production.			Body weight.			Feed.	
		Average for first 10-day period.	Average for last 10-day period.	Average decrease.	Average for first 10-day period.	Average for last 10-day period.	Average gain (+) or loss (−).	Average consumption per cow for entire period.	
								Hay.	Grain.
		Pounds.	*Pounds.*	*Per ct.*	*Pounds.*	*Pounds.*	*Per ct.*	*Pounds.*	*Pounds.*
Tick free	Nos. 1 to 10	176.2	92.1	47.7	719.2	763.4	+6.1	2,500	638
Tick infested	Nos. 11 to 20	177.9	60.6	65.9	707.2	732.9	+3.6	2,437	658
Lightly infested	Nos. 11, 14, 18, 19.	157.5	68.6	56.4	694.4	736.0	+6.0	2,385	585
Moderately infested	Nos. 16, 17	149.4	56.8	61.9	746.1	809.4	+8.5	2,563	569
Heavily infested	Nos. 12, 13, 15, 20.	212.6	54.5	74.3	700.7	691.4	−1.3	2,424	786

COMPARISON OF TICK-FREE AND TICK-INFESTED COWS (ENTIRE GROUPS).

At the beginning of the experimental period the two groups produced practically the same amount of milk—the cows of the tick-free group producing an average of 176.2 pounds during the first 10-day period and those of the tick-infested group an average of 177.9 pounds. During the final 10-day period the cows of the tick-free group produced an average of 92.1 pounds of milk, a decrease of 47.7 per cent from their production during the initial period, while the cows of the tick-infested group produced an average of 60.6 pounds per cow, a decrease of 65.9 per cent when compared with their first 10-day period. It should be noted especially that while the tick-infested cows produced 1 per cent more milk than the tick-free cows in the beginning, they produced only 65.8 per cent as much during the final period. The two groups consumed practically the same

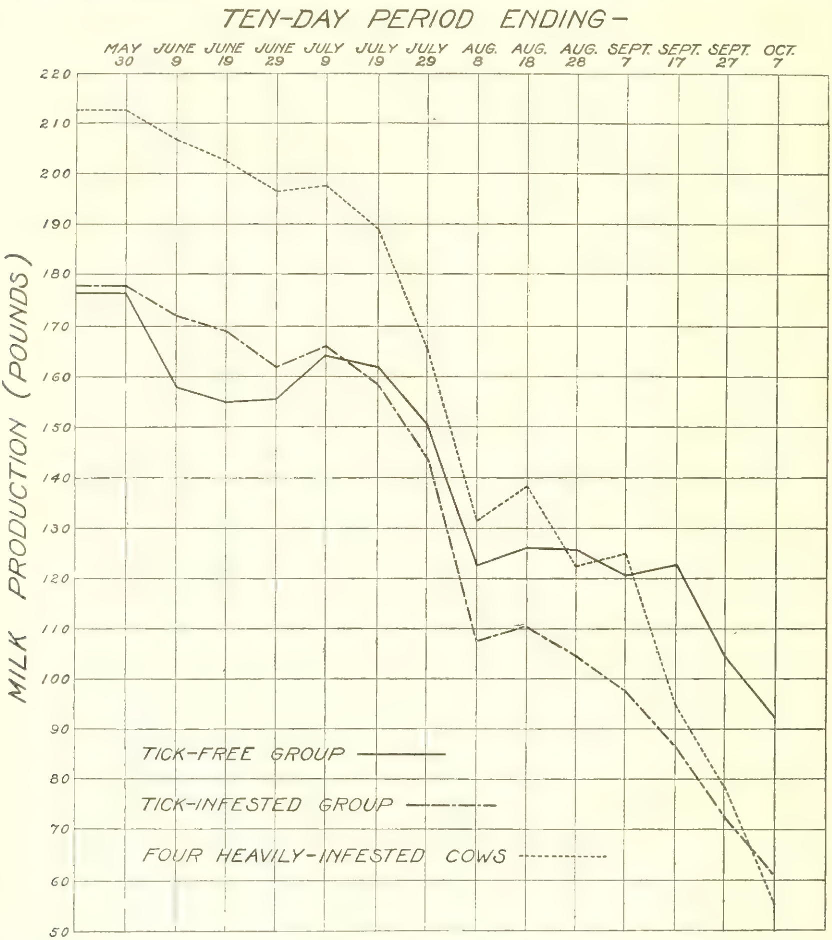

FIG. 5.—Average milk production by 10-day periods of the tick-free and tick-infested groups and of four heavily infested cows.

amount of feed during the entire period. The percentage of fat in the milk of each group increased toward the close of the experiment, that of the infested group showing a slightly greater increase.

At the beginning of the test the tick-free cows weighed on the average 719.2 pounds and the tick-infested 707.2 pounds. During the experimental period each group increased in body weight, but the increase of the tick-free group was greater than that of the tick-infested. During the final 10-day period the cows of the tick-free group averaged 763.4 pounds in weight, an increase of 6.1 per cent, and those of the tick-infested 732.9 pounds, an increase of 3.6 per cent from the initial weight.

In making this comparison it should be remembered that during the entire experimental period the two groups consumed practically an equal amount of nutrients, and that toward the latter part of the experimental period the milk production of the tick-infested group was considerably decreased, so that this group was fed an amount in excess of that required for milk production. Presumably this excess of food would tend to make flesh and thus offset any detrimental effect that the ticks would have upon the body weights.

COMPARISON OF TICK-FREE AND HEAVILY INFESTED GROUPS.

Four cows in the tick-infested group were soon found to be more easily infested than the remaining six. A gross infestation of these four cows was obtained early in the experimental period and was maintained throughout the test. At different times all four suffered from attacks of fever, with an almost total loss of appetite and a falling off in milk flow. One, which suffered from an attack of fever at the end of the experimental period, died shortly after the close of the work.

By referring to Table 3 it will be noticed that there is a much more pronounced decrease in milk production between this group and the tick-free group than when the two entire groups are compared, showing that the heavier degree of infestation results in a proportionately increased injury. This is likewise proved to be true when the body weights of the two groups are compared.

COMPARISON OF TICK-FREE AND LIGHTLY INFESTED GROUPS.

While four cows of the tick-infested group proved to be easily infested, another four of the same group proved to be very resistant. The immature ticks were applied to these four cows with the same care and in as large numbers as they were to the heavily infested animals; in fact, extra efforts were made to obtain a heavy infestation upon these resistant animals. However, at no time during the experimental period were any of the four so heavily infested that the degree of infestation could be classed as gross, and for the greater part of the period none of them was carrying mature ticks. The decrease in milk production was more than in the tick-free cows, but considerably less than in the heavily infested animals.

COMPARISON OF LIGHTLY INFESTED AND HEAVILY INFESTED GROUPS.

While the heavily infested cows produced more milk during the initial period and through the greater part of the experiment, they also consumed more feed than those of the lightly infested group (see Table 3). At the beginning of the experimental period the four heavily infested cows produced an average of 212.6 pounds of milk, while the four lightly infested cows produced an average of 157.5 pounds during the same 10-day period. During the final 10-day period the heavily infested cows produced an average of but 54.5 pounds of milk, a decrease of 74.3 per cent from their production during the initial period. During the same period the lightly infested cows produced an average of 68.6 pounds of milk, a decrease of 56.4 per cent from their production during the first period. While the heavily infested cows produced 35 per cent more milk than the lightly infested during the initial period, they produced only 79.4 per cent as much during the final period. When the two groups are compared with the tick-free groups, it is seen that the lightly infested group produced during the final period of the experiment 81.4 per cent as much milk as the tick-free, while the heavily infested group produced but 57.6 per cent as much. A comparison of the body weights of the two groups shows the heavily infested with an average weight per cow of 700.7 pounds during the initial 10-day period, which decreased to 691.4 pounds per cow, or 1.3 per cent, while the lightly infested cows, with an average weight of 694.4 pounds, increased to 736 pounds per cow, or 6 per cent.

No figures are given on cost of milk production, as the aim was merely to measure the effect of tick infestation on yield of milk and body weight. As the cows were kept in comparatively small inclosures, the cost of milk production was higher than under ordinary conditions when cows are on pasture.

EFFECT OF SPRAYING OR DIPPING IN AN ARSENICAL SOLUTION UPON THE YIELD OF MILK.

At four different times during the experimental period the cows of the tick-free group were sprayed with tick dip B, an arsenical solution. This was done to keep the tick-free cows absolutely free from ticks. Each spraying caused a temporary reduction in the milk yield, as shown by the curves in figure 6. The average yield for the first day after each spraying, when compared with the average of three days preceding spraying, showed percentage reductions in each case as follows: 8.7, 27, 8.3, and 5.7 per cent. It will be noted that the reduction was much the highest for the second spraying. On the day prior to this spraying and for two days thereafter timothy hay was fed, owing to a shortage of alfalfa. This, no doubt, had its influence on the milk yield, as indicated in the excessive shrinkage at that time. From three to five days were required for the cows to return to their normal production. The average of five days after each spraying compared with the average of three days preceding spraying showed reductions, respectively, of 6.2, 21.7, 4.5, and 7.6 per cent. Disregarding the second spraying, the average reduction for five days was 6.1 per cent.

These results with spraying are similar to those obtained with dipping during the 165-day test conducted by J. H. McClain, of the Dairy Division, Bureau of Animal Industry, at Summerville, S. C., in 1912. In this experiment 10 cows were dipped seven times with a solution of tick dip B, the dippings coming at intervals of about 21 days, with an average decline in milk production, for two days, of 10.6 per cent after each of the seven dippings. But apparently the cows became accustomed to the dipping process, for there was no appreciable decrease in the milk flow after the first four dippings except the natural decrease due to the advance in the lactation period. The average decline in production was approximately as follows: After each of the first four dippings, milk 14.8 per cent; fat 8.9 per cent; after each of the last three dippings, milk 1.9 per cent, but an increase of 10.6 per cent in yield of fat.

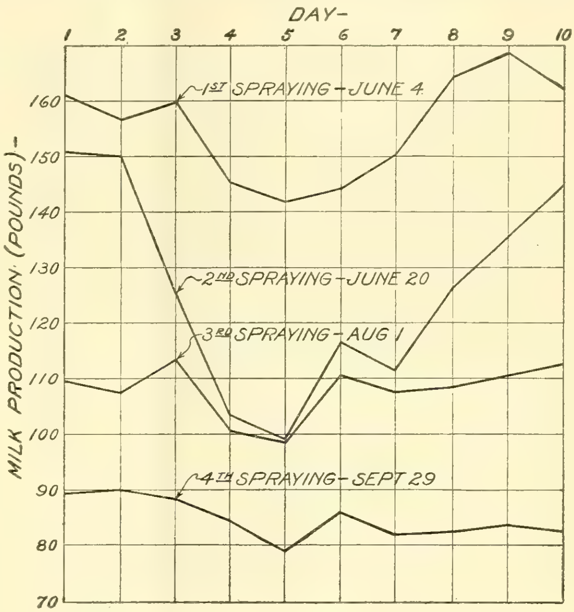

FIG. 6.—Effect of spraying on milk production, showing the average amount of milk produced by the tick-free group for three days before and seven days after each of four sprayings. The unusual decline at the second spraying was probably due to a change in feed.

That the heavily infested cattle in our experiments yielded fully 40 per cent less milk than the check animals at the close of the experiments, and that even those lightly infested gave less by 25 per cent, has been heretofore recorded. Conversely, we may infer that the check cows in this experiment and those regularly dipped in the Summerville experiment gave this additional quantity of milk on account of being kept free from ticks. Had this freedom been obtained without the use of arsenical dips, it is quite certain that an amount of milk equal to 10.6 per cent during one-tenth of the time in the Summerville experiment, and to 6.1 per cent during one-seventh of the time in our experiments, would also have been saved from loss on account of the ticks. These differences emphasize the good results of the use of arsenical dips, and above all, of the necessity for the complete eradication of ticks so that the remedy, which of itself temporarily reduces the flow of milk, will be unnecessary.

SUMMARY AND CONCLUSIONS.

The cattle tick has a decidedly injurious effect upon supposedly immune dairy cattle, the extent of the injury being largely dependent upon the degree of infestation. The effect is more pronounced upon the milk production than upon the body weights when a sufficient supply of food is given.

At the beginning of the test the tick-free and tick-infested groups gave practically the same amounts of milk; at the close the tick-infested gave only 65.8 per cent as much as the tick-free.

The tick-free group gained 6.1 per cent in body weight; the tick-infested gained 3.6 per cent.

Spraying or dipping tick-free cattle in an arsenical solution causes a marked though temporary decrease in milk flow. In this experiment there was an average reduction of 6.1 per cent from the normal milk flow for a period of five days following each of the four applications of the arsenical solution.

Resistance of cattle to infestation by the tick is a variable quality. Of the 10 animals in the tick-infested group, 4 became grossly infested; 2 more so than the average, and the remaining 4 but lightly infested.

The death of cow 15, due to excessive tick infestation, and various recurrences of fever in the other animals, emphasizes the extreme hazard of cattle being continuously subjected to these losses by the tick. Cow 15 was one of the best of the tick-infested group and represented at least a 10 per cent loss from the capital invested in tick-infested cows. Furthermore, the losses observed in this experiment were sustained on rations sufficient to maintain body weights. It is thought that had there been but a scant supply of food, as sometimes occurs when cows are on pasture, the tick-infested cattle would have suffered earlier and probably to a greater degree than they did. The losses in this case were in spite of a good maintenance ration. It is probable that much of the spring losses in cattle now laid to starvation, due to lack of pasturage, is materially aided by blood depletion due to ticks, and that repeated dippings would save many cattle otherwise lost.

These experiments are not extensive enough to furnish an exact measure of the amount of decrease in milk flow due to infestation, but they show that the losses are considerable and vary in immune cows largely in proportion to the extent of infestation, since in all cases the milk flow decreased faster in the heavily infested than in the lightly infested cows. This is additional evidence that the tick is a great hindrance to profitable dairying in the South. Even in so-called immune cattle, ticks cause irritation of the skin and withdraw blood that otherwise would produce milk or meat.

Fever-producing parasites are present in the blood of cattle once infested by ticks, though they may be so few in number that no symptoms of the disease are apparent. The danger from them lurks there, nevertheless, for under certain conditions the parasites may multiply so rapidly as to cause marked disease or death, or they may be transferred by ticks to uninfected animals. Thus the tick constitutes a source of danger, and should be exterminated. Furthermore, eradication must be by cooperative, concerted action. One farmer may free his premises of ticks, but reinfestation is liable to occur at any time from neighboring farms or strange cattle, unless the entire community is free from the tick.

The only means of preventing losses by ticks is through disinfection and clean pastures. While dipping may temporarily diminish the quantity of milk given, in the long run it largely conserves the flow of milk. The arsenical solution should be used to frustrate the great dissemination of ticks during their most favorable season. In infected areas where there is no concerted effort to eradicate ticks it may not be wise to use the solution on slightly infested milch cows.

Methods of exterminating the ticks on the farm are described in Farmers' Bulletin 498, a copy of which will be mailed to anyone on application.

APPENDIX.

RECORDS OF THE EXPERIMENTAL COWS.

The following tables show the records of the experimental cows for the whole test by 10-day periods. Table I gives the results by groups, and Table II the individual records of each of the cows. Originally there were 20 cows in the experiment, 10 in each group, but, as before stated, an injury to one of the tick-free cows necessitated her removal from the test. Therefore, in Table I the tick-free group consists of 9 cows, and in Table II no data are given for cow 4, the cow in question.

TABLE I.—*Group records of experimental cows by 10-day periods.*

TICK-FREE COWS.

Ten-day period ended—	Milk production.			Body weight.	Amount of feed consumed per cow.		Ten-day period ended—	Milk production.			Body weight.	Amount of feed consumed per cow.	
	Average amount of milk.	Average amount of milk fat.	Percentage of milk fat.		Hay.	Grain.		Average amount of milk.	Average amount of milk fat.	Percentage of milk fat.		Hay.	Grain.
1913.	*Lbs.*	*Lbs.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	1913.	*Lbs.*	*Lbs.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*
May 30	176.2	6.58	3.73	719.2	168.9	48.8	Aug. 28	125.5	5.37	4.28	727.6	185.3	45.6
June 9	157.3	5.87	3.73	724.4	173.9	44.0	Sept. 7	120.6	5.00	4.13	738.9	179.4	45.6
June 19	154.4	5.62	3.64	723.4	172.7	46.7	Sept. 17	122.9	5.24	4.26	748.6	172.7	44.5
June 29	155.2	5.84	3.76	694.7	172.3	45.6	Sept. 27	104.2	4.64	4.45	756.8	169.9	44.5
July 9	164.0	6.04	3.69	703.1	189.2	45.6	Oct. 17	92.1	4.42	4.79	763.4	170.8	44.5
July 19	161.7	5.96	3.69	703.1	190.3	45.6							
July 29	150.3	5.98	3.97	706.9	196.1	45.6	Total per cow	1,932.4	76.30	.....	....	2,500.4	637.8
Aug. 8	122.3	4.56	3.72	789.3	182.1	45.6							
Aug. 18	125.7	5.18	4.12	718.0	176.8	45.6							

TICK-INFESTED COWS.

Ten-day period ended—	Average amount of milk.	Average amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Average amount of milk.	Average amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	177.9	6.38	3.58	707.2	163.9	47.7	Aug. 28	104.5	4.15	3.87	715.6	184.5	47.0
June 9	171.6	5.85	3.41	712.8	169.7	44.3	Sept. 7	97.8	3.65	3.73	707.7	170.6	47.0
June 19	168.7	5.93	3.51	726.7	174.8	50.1	Sept. 17	86.9	3.68	4.23	717.0	159.3	45.0
June 29	161.1	5.61	3.48	691.6	174.2	47.0	Sept. 27	72.5	3.43	4.72	721.2	161.6	49.5
July 9	165.9	5.86	3.54	705.6	193.8	47.0	Oct. 7	60.6	2.86	4.71	732.9	145.4	44.6
July 19	158.1	5.55	3.51	702.7	191.1	47.0							
July 29	143.6	5.12	3.56	706.1	190.5	47.7	Total per cow	1,783.3	66.00	.....	....	2,436.8	657.9
Aug. 8	107.6	3.73	3.46	782.3	176.7	47.0							
Aug. 18	110.5	4.20	3.80	728.0	180.7	47.0							

TABLE II.—*Individual records of experimental cows by 10-day periods.*

COW 1, TICK-FREE.

Ten-day period ended—	Milk production.			Body weight.	Feed consumed.		Ten-day period ended—	Milk production.			Body weight.	Feed consumed.	
	Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.		Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.
1913.	*Lbs.*	*Lbs.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	1913.	*Lbs.*	*Lbs.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*
May 30	178.3	7.67	4.30	863.4	172.5	50.0	Aug. 18	106.9	4.65	4.35	870.0	189.5	50.0
June 9	154.8	6.50	4.20	822.0	179.5	45.0	Aug. 28	112.7	4.73	4.20	877.0	200.0	50.0
June 19	150.8	6.33	4.20	822.0	180.0	50.0	Sept. 7	106.6	4.69	4.40	888.0	199.5	50.0
June 29	144.0	5.98	4.15	805.0	180.0	50.0	Sept. 17	106.4	5.00	4.70	902.5	200.0	50.0
July 9	165.5	6.45	3.90	827.0	200.0	50.0	Sept. 27	85.6	4.54	5.30	916.0	198.5	50.0
July 19	159.4	6.06	3.80	813.0	200.0	50.0	Oct. 7	63.2	3.73	5.90	919.7	196.0	50.0
July 29	149.1	6.81	3.90	833.0	220.0	50.0							
Aug. 8	103.3	4.13	4.00	939.0	208.0	50.0	Total	1,786.6	77.27			2,723.5	695.0

COW 2, TICK-FREE.

May 30	146.5	5.27	3.60	664.4	157.5	43.2	Aug. 18	102.0	4.34	4.25	670.0	173.0	40.0
June 9	115.6	4.62	4.00	678.0	159.5	37.0	Aug. 28	99.3	4.37	4.40	671.0	171.5	40.0
June 19	140.1	5.39	3.85	694.0	158.5	40.0	Sept. 7	97.6	4.11	4.20	688.0	165.0	40.0
June 29	130.7	5.23	4.00	656.0	177.5	40.0	Sept. 17	109.1	5.02	4.60	702.3	171.5	40.0
July 9	143.9	5.61	3.90	664.0	178.5	40.0	Sept. 27	91.9	4.14	4.50	718.6	176.0	40.0
July 19	138.6	5.41	3.90	658.0	178.0	40.0	Oct. 7	81.6	4.37	5.35	728.2	174.0	40.0
July 29	132.5	5.17	3.90	657.0	178.5	40.0							
Aug. 8	88.6	3.54	4.00	734.0	162.5	40.0	Total	1,617.9	66.59			2,381.5	560.2

COW 3, TICK-FREE.

May 30	157.2	6.45	4.10	707.5	170.0	50.0	Aug. 18	140.5	5.62	4.00	673.0	180.5	40.0
June 9	149.5	5.38	3.60	682.0	177.5	40.0	Aug. 28	146.2	5.85	4.00	704.0	197.5	40.0
June 19	157.9	5.68	3.60	681.0	177.5	40.0	Sept. 7	139.3	5.36	3.85	702.0	173.5	40.0
June 29	155.2	5.74	3.70	657.0	173.0	40.0	Sept. 17	139.0	5.70	4.10	708.2	159.5	40.0
July 9	160.6	5.94	3.70	677.0	197.5	40.0	Sept. 27	115.6	4.68	4.05	707.9	133.0	40.0
July 19	162.6	5.85	3.60	676.0	200.0	40.0	Oct. 7	111.4	5.24	4.70	695.5	149.0	40.0
July 29	153.8	5.54	3.60	693.0	199.5	40.0							
Aug. 8	131.0	4.72	3.60	745.0	183.5	40.0	Total	2,019.8	77.75			2,471.5	570.0

COW 5, TICK-FREE.

May 30	221.8	7.98	3.60	746.4	171.5	60.0	Aug. 18	118.2	4.92	4.15	758.0	155.0	40.0
June 9	203.4	7.32	3.60	754.0	173.5	53.0	Aug. 28	105.2	4.73	4.50	783.0	154.0	40.0
June 19	192.5	6.74	3.50	762.0	167.5	50.0	Sept. 7	98.5	4.43	4.50	805.0	158.5	40.0
June 29	179.2	6.63	3.70	752.0	155.0	40.0	Sept. 17	95.4	4.29	4.50	810.4	149.5	40.0
July 9	170.4	5.79	3.40	740.0	158.0	40.0	Sept. 27	69.8	3.49	5.00	817.2	153.5	40.0
July 19	156.2	5.62	3.60	723.0	158.5	40.0	Oct. 7	49.2	2.66	5.40	806.8	144.0	40.0
July 29	137.2	4.94	3.60	736.0	158.0	40.0							
Aug. 8	113.9	4.21	3.70	841.0	133.0	40.0	Total	1,910.9	73.75			2,189.5	603.0

COW 6, TICK-FREE.

May 30	268.6	9.13	3.40	729.2	172.5	68.0	Aug. 18	176.0	7.04	4.00	742.0	185.0	70.0
June 9	261.5	8.37	3.20	723.0	179.5	67.0	Aug. 28	189.0	7.56	4.00	733.0	199.5	70.0
June 19	247.7	8.05	3.25	739.0	177.5	70.0	Sept. 7	179.3	7.35	4.10	734.0	190.0	70.0
June 29	233.0	7.46	3.20	719.0	173.5	70.0	Sept. 17	179.9	6.84	3.80	743.0	177.5	60.0
July 9	242.8	8.26	3.40	717.0	199.5	70.0	Sept. 27	150.6	6.02	4.00	754.2	175.5	60.0
July 19	238.7	8.35	3.50	736.0	200.0	70.0	Oct. 7	135.5	5.83	4.30	772.1	175.5	60.0
July 29	218.3	8.51	3.90	729.0	198.5	70.0							
Aug. 8	183.6	6.43	3.50	810.0	180.5	70.0	Total	2,904.5	105.20			2,584.5	945.0

TABLE II.—*Individual records of experimental cows by 10-day periods*—Continued.

COW 7, TICK-FREE.

Ten-day period ended—	Milk production.			Body weight.	Feed consumed.		Ten-day period ended—	Milk production.			Body weight.	Feed consumed.	
	Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.		Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.
1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*	1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*
May 30	138.7	5.13	3.70	660.9	171.0	40.0	Aug. 18	121.4	5.04	4.15	659.0	186.0	40.0
June 9	127.4	5.67	4.45	738.0	176.5	35.0	Aug. 28	121.6	5.84	4.80	647.0	198.0	40.0
June 19	128.2	4.87	3.80	652.0	179.5	40.0	Sept. 7	115.7	4.98	4.30	651.0	198.5	40.0
June 29	133.0	5.19	3.90	642.0	179.5	40.0	Sept. 17	121.5	5.29	4.35	661.5	181.5	40.0
July 9	147.5	5.97	4.05	644.0	198.0	40.0	Sept. 27	108.9	4.90	4.50	678.9	178.5	40.0
July 19	146.8	5.87	4.00	633.0	197.0	40.0	Oct. 7	105.1	5.04	4.80	685.9	180.0	40.0
July 29	138.8	5.69	4.10	646.0	210.0	40.0							
Aug. 8	120.6	4.82	4.00	704.0	187.5	40.0	Total	1,775.2	74.30	.....	....	2,621.5	555.0

COW 8, TICK-FREE.

May 30	174.1	6.27	3.60	839.9	175.0	48.0	Aug. 18	137.7	4.99	4.35	818.0	192.5	50.0
June 9	153.4	5.83	3.80	840.0	180.0	44.0	Aug. 28	134.1	6.30	4.70	864.0	200.0	50.0
June 19	151.3	5.67	3.75	842.0	179.5	50.0	Sept. 7	121.2	5.33	4.40	872.0	200.0	50.0
June 29	154.0	6.01	3.90	785.0	180.0	50.0	Sept. 17	118.0	5.78	4.90	882.5	197.0	50.0
July 9	160.2	6.09	3.80	807.0	200.0	50.0	Sept. 27	105.5	5.28	5.00	893.2	200.0	50.0
July 19	157.7	5.99	3.80	813.0	200.0	50.0	Oct. 7	90.8	4.77	5.25	922.6	200.0	50.0
July 29	155.1	6.36	4.10	816.0	220.0	50.0							
Aug. 8	123.4	5.06	4.10	914.0	216.5	50.0	Total	1,936.5	79.73	.....	....	2,740.5	692.0

COW 9, TICK-FREE.

May 30	133.7	5.21	3.90	500.5	157.5	31.6	Aug. 18	132.9	5.71	4.30	523.0	169.5	40.0
June 9	115.8	4.40	3.80	505.0	160.0	33.0	Aug. 28	125.6	5.02	4.00	541.0	168.0	40.0
June 19	118.1	4.25	3.60	540.0	160.0	40.0	Sept. 7	124.5	4.73	3.80	541.0	152.5	40.0
June 29	132.8	5.05	3.80	508.0	156.0	40.0	Sept. 17	126.2	5.17	4.10	544.5	139.0	40.0
July 9	144.1	5.55	3.85	502.0	172.0	40.0	Sept. 27	112.4	4.83	4.30	547.4	134.0	40.0
July 19	145.0	4.93	3.40	523.0	179.5	40.0	Oct. 7	103.2	4.44	4.30	552.7	139.0	40.0
July 29	140.4	5.34	3.80	519.0	180.0	40.0							
Aug. 8	119.6	3.95	3.30	596.0	162.0	40.0	Total	1,774.3	68.58	.....	....	2,229.0	554.6

COW 10, TICK-FREE.

May 30	167.3	6.11	3.65	760.8	173.0	48.0	Aug. 18	95.5	4.30	4.50	749.0	160.0	40.0
June 9	134.3	4.78	3.55	778.0	179.5	42.0	Aug. 28	95.8	3.93	4.10	729.0	179.0	40.0
June 19	103.1	3.61	3.50	779.0	174.5	40.0	Sept. 7	102.4	4.05	3.95	769.0	177.0	40.0
June 29	135.2	5.27	3.90	727.0	176.0	40.0	Sept. 17	110.4	4.04	3.65	772.6	178.5	40.0
July 9	140.8	4.79	3.40	750.0	199.0	40.0	Sept. 27	97.3	3.89	4.00	778.9	180.0	40.0
July 19	149.9	5.55	3.70	753.0	200.0	40.0	Oct. 7	89.2	3.66	4.10	787.2	180.0	40.0
July 29	144.7	5.50	3.80	733.0	200.0	40.0							
Aug. 8	117.1	4.22	3.60	822.0	181.0	40.0	Total	1,683.0	63.70	.....	....	2,537.5	570.0

COW 11, TICK-INFESTED.

May 30	208.2	8.74	4.20	813.9	175.5	54.8	Aug. 18	108.7	4.29	3.95	816.0	189.5	40.0
June 9	180.4	7.04	3.90	818.0	179.0	52.0	Aug. 28	109.0	5.01	4.60	829.0	200.0	40.0
June 19	169.3	6.77	4.00	842.0	180.0	52.0	Sept. 7	113.7	4.89	4.30	829.0	196.0	40.0
June 29	152.1	6.24	4.10	800.0	180.5	40.0	Sept. 17	109.1	5.02	4.60	836.1	198.5	40.0
July 9	172.5	6.90	4.00	818.0	200.0	40.0	Sept. 27	98.9	4.75	4.80	857.9	197.5	49.0
July 19	145.4	5.39	3.70	813.0	198.0	40.0	Oct. 7	103.2	4.95	4.80	862.4	198.5	50.0
July 29	141.9	5.53	3.90	807.0	200.0	40.5							
Aug. 8	101.0	3.64	3.60	909.0	183.0	40.0	Total	1,913.4	79.16	.....	....	2,676.0	618.3

TABLE II.—*Individual records of experimental cows by 10-day periods*—Continued.

COW 12, TICK-INFESTED.

Ten-day period ended—	Milk production.			Body weight.	Feed consumed.		Ten-day period ended—	Milk production.			Body weight.	Feed consumed.	
	Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.		Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.
1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*	1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*
May 30	221.0	7.62	3.45	640.2	154.5	58.0	Aug. 18	135.5	5.01	3.70	620.0	172.0	60.0
June 9	213.6	6.73	3.15	643.0	171.5	55.0	Aug. 28	122.2	4.77	3.90	622.0	166.0	60.0
June 19	209.7	7.34	3.50	675.0	179.0	62.0	Sept. 7	130.1	4.55	3.50	622.0	161.0	60.0
June 29	200.3	6.01	3.00	648.0	181.5	60.0	Sept. 17	118.0	4.90	4.15	622.0	154.5	60.0
July 9	199.0	6.57	3.30	623.0	192.5	60.0	Sept. 27	112.4	5.17	4.60	626.7	164.5	60.0
July 19	192.9	6.75	3.50	623.0	191.0	60.0	Oct. 7	110.2	5.07	4.60	655.3	174.5	60.0
July 29	161.0	6.08	3.80	628.0	173.0	61.5							
Aug. 8	143.0	5.15	3.60	715.0	169.0	60.0	Total	2,268.9	81.72			2,404.5	836.5

COW 13, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	224.6	8.53	3.80	587.7	152.5	58.0	Aug. 18	153.5	6.14	4.00	591.0	189.0	60.0
June 9	224.9	8.55	3.80	576.0	156.0	56.0	Aug. 28	146.2	6.14	4.20	594.0	184.5	60.0
June 19	219.6	8.23	3.75	590.0	178.0	62.0	Sept. 7	134.5	5.65	4.20	564.0	158.5	60.0
June 29	213.9	7.91	3.70	567.0	179.0	60.0	Sept. 17	116.0	5.63	4.85	565.7	136.5	50.0
July 9	213.7	8.65	4.05	582.0	195.5	60.0	Sept. 27	110.6	5.64	5.10	566.5	139.5	50.0
July 19	211.2	8.03	3.80	578.0	200.0	60.0	Oct. 7	103.0	5.67	5.50	573.9	139.5	50.0
July 29	190.8	7.63	4.00	590.0	197.5	61.5							
Aug. 8	148.9	5.81	3.90	649.0	191.5	60.0	Total	2,411.4	98.21			2,397.5	807.5

COW 14, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	128.7	4.50	3.50	664.1	166.5	32.0	Aug. 18	95.0	3.74	3.95	665.0	178.0	40.0
June 9	125.2	4.07	3.25	655.0	168.0	32.0	Aug. 28	101.5	3.86	3.80	651.0	182.0	40.0
June 19	119.6	4.19	3.50	676.0	177.5	42.0	Sept. 7	102.6	3.28	3.20	669.0	173.0	40.0
June 29	116.7	4.08	3.50	648.0	160.0	40.0	Sept. 17	112.1	4.09	3.65	684.6	179.5	40.0
July 9	120.0	4.20	3.50	655.0	189.5	40.0	Sept. 27	99.1	4.16	4.20	696.0	176.5	49.0
July 19	120.5	4.10	3.40	665.0	180.0	40.0	Oct. 7	101.9	4.08	4.00	707.0	172.5	50.0
July 29	112.9	3.84	3.40	640.0	180.0	40.5							
Aug. 8	85.2	2.90	3.40	730.0	168.5	40.0	Total	1,541.0	55.09			2,451.5	565.5

COW 15, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	250.4	8.01	3.20	865.6	176.0	68.0	Aug. 18	163.9	5.41	3.30	853.0	188.5	70.0
June 9	247.5	7.18	2.90	863.0	180.0	62.0	Aug. 28	168.3	6.06	3.60	881.0	196.0	70.0
June 19	244.9	7.47	3.05	886.0	180.0	72.0	Sept. 7	151.1	4.53	3.00	818.0	183.5	70.0
June 29	235.9	7.55	3.20	816.0	181.5	70.0	Sept. 17	120.2	4.21	3.50	832.2	174.5	60.0
July 9	240.6	6.98	2.90	864.0	199.0	70.0	Sept. 27	79.7	3.75	4.70	825.9	156.0	60.0
July 19	235.1	7.52	3.20	868.0	200.0	70.0	Oct. 7	5.0	0.24	4.70	801.8	14.0	6.0
July 29	207.9	6.65	3.20	846.0	217.0	70.5							
Aug. 8	170.7	5.29	3.10	925.0	194.5	70.0	Total	2,521.2	80.85			2,440.5	888.5

COW 16, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	154.3	5.39	3.50	763.0	170.0	40.0	Aug. 18	107.7	4.20	3.90	783.0	188.5	40.0
June 9	162.8	5.70	3.50	757.0	176.5	38.0	Aug. 28	97.6	3.90	4.00	776.0	197.0	40.0
June 19	154.5	4.94	3.20	768.0	179.5	42.5	Sept. 7	89.3	3.75	4.20	749.0	182.5	40.0
June 29	145.9	4.96	3.40	741.0	182.0	40.0	Sept. 17	84.2	3.37	4.00	772.5	172.0	40.0
July 9	153.6	4.99	3.25	752.0	195.5	40.0	Sept. 27	74.1	3.45	4.65	788.0	177.0	40.0
July 19	156.8	4.70	3.00	735.0	200.0	40.0	Oct. 7	64.0	3.20	5.00	811.7	176.0	40.0
July 29	140.9	4.65	3.30	764.0	200.0	40.5							
Aug. 8	117.3	3.75	3.20	831.0	183.5	40.0	Total	1,703.0	60.95			2,580.0	561.0

TABLE II.—*Individual records of experimental cows by 10-day periods*—Continued.

COW 17, TICK-INFESTED.

Ten-day period ended—	Milk production.			Body weight.	Feed consumed.		Ten-day period ended—	Milk production.			Body weight.	Feed consumed.	
	Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.		Amount of milk.	Amount of milk fat.	Percentage of milk fat.		Hay.	Grain.
1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*	1913.	*Lbs.*	*Lbs.*	*P.ct.*	*Lbs.*	*Lbs.*	*Lbs.*
May 30	144.4	5.05	3.50	729.2	176.0	40.0	Aug. 18	98.8	3.89	3.95	778.0	186.5	40.0
June 9	134.3	4.53	3.35	813.0	179.5	36.0	Aug. 28	78.8	2.99	3.80	763.0	184.0	40.0
June 19	142.1	5.04	3.55	762.0	178.5	42.5	Sept. 7	67.9	2.82	4.15	760.0	170.0	40.0
June 29	137.4	4.67	3.40	717.0	180.5	40.0	Sept. 17	71.4	3.21	4.50	764.8	169.5	40.0
July 9	144.2	5.48	3.80	744.0	200.0	40.0	Sept. 27	59.0	2.92	4.95	775.8	172.0	49.0
July 19	136.2	4.53	3.40	726,0	200.0	40.0	Oct. 7	49.5	2.40	4.85	807.2	170.0	50.0
July 29	126.1	4.16	3.30	746.0	199.0	40.5							
Aug. 8	92.1	3.13	3.40	833.0	181.0	40.0	Total	1,482.2	54.82			2,546.5	578.0

COW 18, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	145.7	5.25	3.60	624.3	155.0	43.2	Aug. 18	79.6	2.99	3.75	657.0	173.0	40.0
June 6	152.5	5.49	3.60	623.0	149.5	36.0	Aug. 28	67.1	2.55	3.80	658.0	182.0	40.0
June 19	157.5	5.75	3.65	650.0	155.0	42.0	Sept. 7	50.7	1.93	3.80	663.0	159.5	40.0
June 29	151.1	5.59	3.70	618.0	157.5	40.0	Sept. 17	30.7	1.20	3.90	668.9	137.5	40.0
July 9	147.8	5.32	3.60	640.0	185.5	40.0	Sept. 27	5.0	0.18	3.65	680.9	144.5	49.0
July 19	137.8	5.24	3.80	640.0	180.0	40.0	Oct. 7	Dry.	Dry.	Dry.	692.9	137.5	50.0
July 29	128.4	4.88	3.80	653.0	178.5	40.5							
Aug. 8	75.0	2.78	3.70	715.0	159.0	40.0	Total	1,328.9	49.15			2,254.0	580.7

COW 19, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	147.4	4.86	3.30	675.3	157.0	40.0	Aug. 18	101.3	3.85	3.80	763.0	160.5	40.0
June 9	134.8	4.31	3.20	649.0	157.5	37.0	Aug. 28	100.1	4.00	4.00	633.0	161.5	40.0
June 19	132.5	4.57	3.45	678.0	160.0	42.0	Sept. 7	93.5	3.74	4.00	654.0	154.0	40.0
June 29	122.1	4.40	3.60	653.0	159.0	40.0	Sept. 17	82.1	3.53	4.30	654.4	134.5	40.0
July 9	130.1	4.68	3.60	640.0	180.0	40.0	Sept. 27	74.3	3.45	4.65	666.3	144.0	49.0
July 19	127.5	4.97	3.90	631.0	162.0	40.0	Oct. 7	69.2	3.18	4.60	681.8	133.5	50.0
July 29	123.1	4.31	3.50	643.0	160.0	40.5							
Aug. 8	79.9	2.50	4.00	703.0	138.0	40.0	Total	1,517.9	56.35			2,161.5	578.5

COW 20, TICK-INFESTED.

Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.	Ten-day period ended—	Amount of milk.	Amount of milk fat.	Percentage of milk fat.	Body weight.	Hay.	Grain.
May 30	154.4	5.87	3.80	709.1	176.0	43.2	Aug. 18	61.0	2.47	4.05	754.0	181.5	40.0
June 9	140.0	4.90	3.50	731.0	179.0	39.0	Aug. 28	53.7	2.26	4.20	752.0	192.0	40.0
June 19	137.0	4.93	3.60	740.0	180.0	42.0	Sept. 7	44.8	2.37	5.30	749.0	168.0	40.0
June 29	135.2	4.73	3.50	708.0	180.5	40.0	Sept. 17	25.1	1.63	6.50	748.8	135.5	40.0
July 9	137.3	4.81	3.50	738.0	200.0	40.0	Sept. 27	11.4	0.79	6.90	727.6	145.5	40.0
July 19	117.8	4.24	3.60	748.0	200.0	40.0	Oct. 7	Dry.	Dry.	Dry.	734.6	137.5	40.0
July 29	102.9	3.50	3.40	744.0	200.0	40.5							
Aug. 8	62.9	2.20	3.50	813.0	178.5	40.0	Total	1,183.5	44.70			2,454.0	564.7

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THE USE OF BACILLUS BULGARICUS IN STARTERS FOR MAKING SWISS OR EMMENTAL CHEESE.

By C. F. Doane and E. E. Eldredge,
Of the Dairy Division, Bureau of Animal Industry.

INTRODUCTION.

The Swiss-cheese industry was introduced and is still carried on in the United States by settlers from Switzerland who were cheesemakers in their native land. Not many of them remain in the business in this country for any length of time, however, mainly because of the long hours of labor necessary under the present system of making cheese twice a day. But this system was inevitable until a sufficient knowledge of fundamental principles could be obtained so that the method of making the cheese could be altered without injuring the quality of the product. As an art Swiss cheesemaking is very highly developed, but it is based on empirical methods. Few scientific principles have been found that are a help to the cheesemakers even in Switzerland, where the industry has been well established for a long time.

Although some very fine cheese of the Swiss or Emmental type has been made in the United States, the quality has not averaged so high as that of the foreign-made cheese. The feed, pastures, climate, topography, and other conditions, so different from those in Switzerland, where the present system of Swiss-cheese manufacture was developed, naturally call for changes which could not be made in the absence of a knowledge of the causes which underlie the processes of cheesemaking. Another contributory cause of low-grade American-made cheese has been the inadaptability of many of the cheese factories; their fitness for cheesemaking has sometimes been sacrificed to cheap construction. So many difficulties have been experienced that cheesemakers were led to believe that it was impossible to make a good Swiss cheese except in a few localities. Some believed, in fact, that there was no place in the United States where

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Note.—This bulletin reports experimental work showing how to control undesirable fermentations and thus to provide a remedy for the most serious troubles which occur in making Swiss or Emmental cheese. It is of interest chiefly to manufacturers of that type of cheese.

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the product would equal in quality that made in Europe, since the same methods were used on both sides of the Atlantic.

The most serious trouble of the cheesemaker occurred during the cold months, which led to the practice of making cheaper varieties of cheese in the spring and fall and closing down the factory for four months in the winter. This, of course, is a considerable handicap to the industry, and would not be necessary if there were sufficient information concerning the origin of and remedy for the faults in manufacture. These unsatisfactory conditions led to the investigations reported in this bulletin, since it was believed that the present faulty methods might be corrected, provided the real causes of cheese defects were discovered.

In the absence of exact knowledge it was natural that erroneous theories should become prevalent in regard to the feeding of the cows, the care of the milk, and the handling of the cheese; but as they were based on practical experience it has not been found advisable to set them aside without investigation. Apparently very unimportant changes made in handling the cheese were found to result in great changes in the quality of the finished product, and although changes in methods are necessary in order to produce the best quality of cheese, it is unwise to advise the cheesemaker to change his methods without substantial proof of the value of the change.

The main trouble in making Swiss cheese is known to be caused by the development of undesirable types of microorganisms, some of which produce abnormal gas, causing what is known as "nissler" or "pressler" cheese. These undesirable organisms in Swiss cheese cause a lack of uniformity in the formation of the eyes. In some cases no eyes whatever are developed; this trouble is probably due to the absence of certain desirable types. At the beginning of this work it was thought that these faults might be overcome by the proper use of starters, which have become general in buttermaking, and their value has been frequently demonstrated. They have also been used to some extent in the making of Cheddar cheese. Unconsciously the makers of Swiss cheese have used starters with the rennet, a practice which has at times been of great value. But while the rennet starter has been the cause of much help, it has also caused trouble when the helpful species of bacteria usually present have for some reason been weakened. The full benefit of the starter was not obtained, in any event, since less than one-fourth of 1 per cent of rennet was used.

THE SIGNIFICANCE OF BACILLUS BULGARICUS IN MAKING SWISS CHEESE.

In selecting a starter for making Swiss cheese it is at once apparent that certain characteristics are desirable to make its use possible with the method of manufacture employed. The curd for Swiss cheese is cooked at a comparatively high temperature, 126° to 136° F., and is cooled very gradually while the cheese is in press. This treatment checks temporarily the growth of most species of bacteria, including the lactic-acid bacteria, which are used for starters in the making of butter and Cheddar cheese.

The *Bacillus bulgaricus* group of bacteria has the qualifications which apparently fit in with the manufacturing process of Swiss cheese. Investigators have found a wide variation in the temperatures at which different varieties will grow and in the amount and rapidity of acid formation. The presence of this group of bacteria in the rennet preparations was first recognized by Freudenreich and Jensen,[1] who studied it and named it *Bacillus casei* ε. They came to the conclusion that it was largely responsible for the normal ripening of the cheese, but Jensen apparently receded from this position a few years afterwards, though he still advocated the use of *B. casei* ε in the preparation of rennet for the purpose of suppressing the growth of undesirable bacteria in the rennet solution. He has been supported in this by many of the European authorities, and pure cultures of *B. bulgaricus* have been furnished extensively to makers of Swiss cheese for this purpose.

Peter and Held,[2] in discussing the sources of infection causing troubles with Swiss cheese and the influence of the rennet solution on the cheese, suggested the possibility of the cultures in the rennet suppressing undesirable gas-forming types of bacteria in the cheese.

Gratz,[3] in some laboratory tests, found that a culture of *Bacillus bulgaricus* inhibited the growth of bacteria of the coli-aerogenes group in milk held at a temperature of 40° C. (104° F.).

Burri,[4] in discussing the relative merits of commercial acid and pure cultures of *Bacillus bulgaricus* in making up the whey rennet solution, points out that *B. bulgaricus* suppressed the growth of gas-forming bacteria in the whey rennet.

Thöni[5] showed the influence of *B. bulgaricus* in making good rennet. He reported some experiments in which rennet containing *B. bulgaricus* made good cheese, while cheese made with the natural rennet without this bacillus was gassy, evidently because the gas-producing bacteria made a very heavy growth in the rennet.

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[1] Freudenreich, Edward von, and Jensen, Orla. Die Bedeutung der Milchsäurefermente für die Bildung von Eiweisszersetzungsprodukten in Emmenthalerkäsen, nebst einigen Bemerkungen über die Reifungsvorgänge. Landwirtschaftliches Jahrbuch der Schweiz, vol. 13, p. 169–197. Bern, 1899.

[2] Peter, A., and Held, J. Praktische Anleitung zur Fabrikation und Behandlung des Emmentalerkäses. Second edition. Bern, 1910.

[3] Gratz, Otto. Studien über die Antibiose zwischen Bacterium casei ε und den Bakterien der Coli-Aerogenes-Gruppe. Zeitschrift für Gärungsphysiologie allgemeine, landwirtschaftliche und technische Mykologie, vol. 1, no. 3, p. 256–281. Berlin, June, 1912.

[4] Burri, Robert, Reinkulturen oder Säuremischung beim Labansatz? Molkerei Zeitung, vol. 22, no. 33, p. 387–389. Berlin, 1912.

[5] Thöni, Johannes. Bakteriologische studien über Labmägen und Lab. Ein Beitrag zur Kenntnis der Bereitung des Käsereilabes. Landwirtschaftliches Jahrbuch der Schweiz, vol. 20, p. 181–242. Bern, 1906.

Jensen[1] advised the use of a streptococcus in connection with *B. bulgaricus* as a starter for suppressing undesirable bacterial growths in the cheese, but offered no proof of the efficiency of this combination of cultures.

Though it is generally believed that it is the lactic acid produced by different bacteria that gives different varieties their value in preventing the growth of undesirable forms of germ life, this assumption is seriously questioned by some bacteriologists, who think it possible that the formation of lactic acid is incidental and is not the active inhibiting principle.

White and Avery[2] point out that cultures of *B. bulgaricus* grow at relatively high temperatures, forming acid as high as 50° C. (122° F.). They also show that relatively high percentages of acid are formed in milk, reaching as high as 3.1 per cent.

Hastings and Hammer[3] give 4.09 per cent as the maximum amount of acid found in milk. They find that *B. bulgaricus* is distributed very widely and generally in dairy products of all kinds. Mention is made especially of its presence in the milk and whey at Swiss-cheese factories.

Heinemann and Hefferan[4] also noted the general distribution of *B. bulgaricus*, its high growing temperature and its ability to form acid in milk.

The authors quoted found a very great difference in the maximum amount and the rapidity of acid formation of different cultures. Cultures also lose their ability to form acid to a great extent when carried under laboratory conditions. The growth of *Mycoderma* on the surface of the whey starter greatly facilitates the growth of the *B. bulgaricus* culture used. Thöni[5] in some tests with the *Mycoderma* found that while the whey culture of *B. bulgaricus* without the *Mycoderma* showed at the end of 24 hours 7,000,000 and 18,000,000 bacteria per cubic centimeter, with the *Mycoderma* the numbers were 136,000,000 and 200,000,000, respectively, and the increase of acid with the *Mycoderma* was more than one-half.

In our own work we have found that *B. bulgaricus* can form as high as 2 per cent acid in whey, and we found that with the culture iso-

[1] Jensen, Orla. Ueber die im Emmentalerkäse stattfindende Milchsäuregärung. Milchwirtschaftliches Zentralblatt, vol. 2, no. 9, p. 393–414. Leipzig, Sept., 1906.

[2] White, Benjamin, and Avery, Oswald T. Observations on certain lactic-acid bacteria of the so-called bulgaricus type. Centralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten, Abteilung 2, vol. 25, no. 5/9, p. 161–178. Jena, Nov. 30, 1909.

[3] Hastings, Edwin George, and Hammer, B. W. The occurrence and distribution of organisms similar to *B. bulgaricus* of yogurt. Centralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten, Abteilung 2, vol. 25, no. 14/18, p. 419–426. Jena, Dec. 22, 1909.

[4] Heinemann, Paul Gustav, and Hefferan, Mary. A study of *Bacillus bulgaricus*. Journal of Infectious Diseases, vol. 6, no. 3, pp. 304–318. Chicago, June 12, 1909.

[5] Loc. cit.

lated at Albert Lea, Minn., the most favorable temperature was 49° C.
in making Swiss cheese began in the winter of 1910–11 at Albert Lea,

EXPERIMENTS WITH BACILLUS BULGARICUS STARTERS.

Our experiments with cultures of *Bacillus bulgaricus* as a starter in making Swiss cheese began in the winter of 1910–11 at Albert Lea, Minn. The work was continued at State College, Pa., and finally completed in the laboratories at Washington. The milk delivered for cheesemaking at Albert Lea was of very poor quality, being very gassy, and it was impossible to secure any that was not badly infected. A long series of experiments in pasteurization had not proved entirely successful, and experiments to discover a bacterial culture that would prove efficient in suppressing gas-forming bacteria were begun. A number of different cultures of *B. bulgaricus* were used under varying conditions and at all seasons of the year.

In Table 1 are given the results obtained with *B. bulgaricus* cultures that proved efficient in suppressing gas-forming types of bacteria when used in what would probably be considered as reasonable amounts of starter; that is, where the starter was less than 2 per cent of the total amount of milk used. The cultures used were obtained from different sources. Culture 39a was very active and was the only culture of *B. bulgaricus* used at Albert Lea, Minn.[1] Cultures I S and 44H were isolated in the Washington laboratories.

In the experiments recorded in Tables 1 and 2 all the milk was first put into one kettle, where it was thoroughly stirred and then divided. As the kettle and all other apparatus used were thoroughly cleaned before using, identical conditions in both lots of milk were insured.

Probably every lot of milk used in these experiments was as badly contaminated with gas-forming bacteria as the mixed milk would be in any commercial Swiss-cheese factory on any day of the year. Nevertheless from this milk, by the use of these starters, we were enabled to make a perfectly sound cheese that did not develop into a "nissler" or "pressler."

The milk used at the Washington laboratories came from the herd owned by the Dairy Division and was almost free from the faults common to ordinary factory milk. There may have been no occasion for using a starter with this milk to suppress gas-forming bacteria. At this time culture 39a, by being carried in the laboratory, had lost much of its power to form acid, but was still active enough to retain its efficiency in suppressing undesirable gas formers. A

[1] This culture was isolated by Mr. B. J. Davis, of this laboratory, who was in search of a strain of high acid-producing bacteria for pure cultures in buttermaking. This culture produced 3 per cent of acid in milk, but only 2 per cent in whey.

few additional tests were made with *Bacillus bulgaricus* starter, using fresh cow manure for contamination, and with cheese 31, Table 1, enough manure was added to the milk to give it a slight color. The result of this test, in which culture W was used, is seen in Plate I, which illustrates the efficiency of this starter on gas-producing bacteria. This test was perhaps no more severe than many others that were made. The two cheeses were cut 24 hours after making from the same lot of badly contaminated milk. The upper cheese shows the effect of the starter; the lower cheese, made without starter, is badly "nissler." This experiment was not made to determine whether or not contaminated milk would make good cheese, but to test the effect of the starter on milk heavily inoculated with gas-producing bacteria. The cheese, as was to be expected, was not a normal cheese; it had a strong, bitter taste, but abnormal gas formation was entirely suppressed.

TABLE 1.—*Showing suppression of gas formation in Swiss cheese by the use of Bacillus bulgaricus cultures in normal amounts.*

Cheese No.	Culture No.	Starter.		Condition of cheese.	
		Amount.	Acidity.	Starter.	No starter.
		Per cent.	*Per cent.*		
1	39 a	1	1	No gas	
2	39 a	1	1.2	do	
3	39 a	1	.9	Slightly gassy	Very gassy.
4	39 a	1	1.1	Edge gassy	Do.
5	39 a	1	1.2	No gas	Do.
6	39 a	1	1.1	do	Do.
7	39 a	1	1.4	do	Do.
8	39 a	1	1.0	do	Do.
10	39 a	1.5	.5	do	Gassy.
11	39 a	1.5	.5	do	Do.
12	39 a	1.5	.5	do	Very gassy.
13	39 a	.66	.8	Slightly gassy	Do.
15	I S	1.5	.5	Edge gassy	Gassy.
16	I S	1.5	.5	do	Very gassy.
17	I S	1.5	.6	do	Do.
18	I S	1	.6	No gas	Gassy.
19	I S	1	.5	Slightly gassy	Very gassy.
20	44 H	1	.5	No gas	Gassy.
21	44 H	1	.4	do	Slightly gassy.
22	44 H	1	.6	do	Do.
23	44 H	1	.5	do	Gassy.
24	44 H	1	.3	do	Slightly gassy.
25	44 H	1.5	.5	do	Very gassy.
26	44 i	1.5	.5	Edge gassy	Gassy.
27	44 i	1.5	.5	do	Do.
28	44 i	.75	.4	Slightly gassy	Very gassy.
29	44 i	1.5	.5	No gas	Gassy.
30	44 i	1.5	.4	Edge gassy	Do.
31	W	2.0	.1	No gas	Very gassy.

Attention is called to cheeses 4, 15, 16, and 17, Table 1, where the outside surface or "edge" of the cheese to perhaps a half inch or 1 inch was badly gassy, while the center was entirely free from gas. The outside portion becomes cooled, allowing the gas-producing bacteria to damage this part of the cheese, while the inside portion remains at a temperature more favorable for the growth of *B. bulgaricus*. This illustrates excellently the fact that the long-continued high temperature of cooking and pressing the curd is necessary to obtain the best results with *Bacillus bulgaricus.*

Table 2 gives the results with starters made from a *B. bulgaricus* culture that did not prove efficient unless used in comparatively large quantities, as much as 4 per cent of starter made with culture B being required thoroughly to suppress gas formers. Culture B was a common type of *B. bulgaricus*, causing stringiness; that is, stringy or slimy milk and whey. This was the only culture of *B. bulgaricus* used that gave questionable results.

TABLE 2.—*Effect of Bacillus bulgaricus starter (Culture B) on suppression of gas formation in Swiss cheese.*

Cheese No.	Culture No.	Starter.		Condition of cheese.	
		Amount.	Acidity.	Starter.	No starter.
		Per cent.	*Per cent.*		
1	B	1	0.3	No gas	Very gassy.
2	B	.66	1.2	Very gassy	Do.
3	B	.66	1.4	Gassy	Do.
4	B	.66	1.5	Very gassy	Do.
5	B	.5	2.4	do	Do.
6	B	1	.7	Slightly gassy	Do.
7	B	3	.8	Edge gassy	Do.
8	B	4	.9	No gas	Do.

More than 100 cheeses were made from milk known to be badly contaminated in which the starters showed positive results in securing good cheese. Only those cases in which companion cheeses were made from the same milk, one with and one without the starter, have been included in Tables 1 and 2.

Table 3 contains the results with starters made from types of bacteria which cause the normal souring of milk and which are usually found in commercially pure cultures advertised for use in creameries and Cheddar-cheese factories. A few trials were made with starters prepared from these cultures and another commercial culture, but with poor results.

TABLE 3.—*Results of using starters made from common lactic types of bacteria in making Swiss cheese.*

Cheese No.	Culture No.	Starter.		Condition of cheese.	
		Amount.	Acidity.	Starter.	No starter.
		Per cent.	*Per cent.*		
1	E	4	0.6	Very gassy	
2	E	4	.6	do	
3	E	2	.6	do	
4	E	2	.6	do	
5	E	4	.6	do	
6	S M	1	.6	do	
7	S M	1	.6	do	
8	S M	1	.6	do	
9	S M	2	.6	do	
10	S M	4	.6	Pin holes	

Some experiments not recorded in these tables showed very definitely that the temperature of cooking the curd had a very material influence on the effectiveness of *Bacillus bulgaricus* starters. In a number of tests it was found that cheeses cooked at 125° F. or above were entirely free from gas. It appears probable that the higher cooking temperature served to check the growth of undesirable bacteria for a longer period or until the *Bacillus bulgaricus* secured a sufficient start to check their growth.

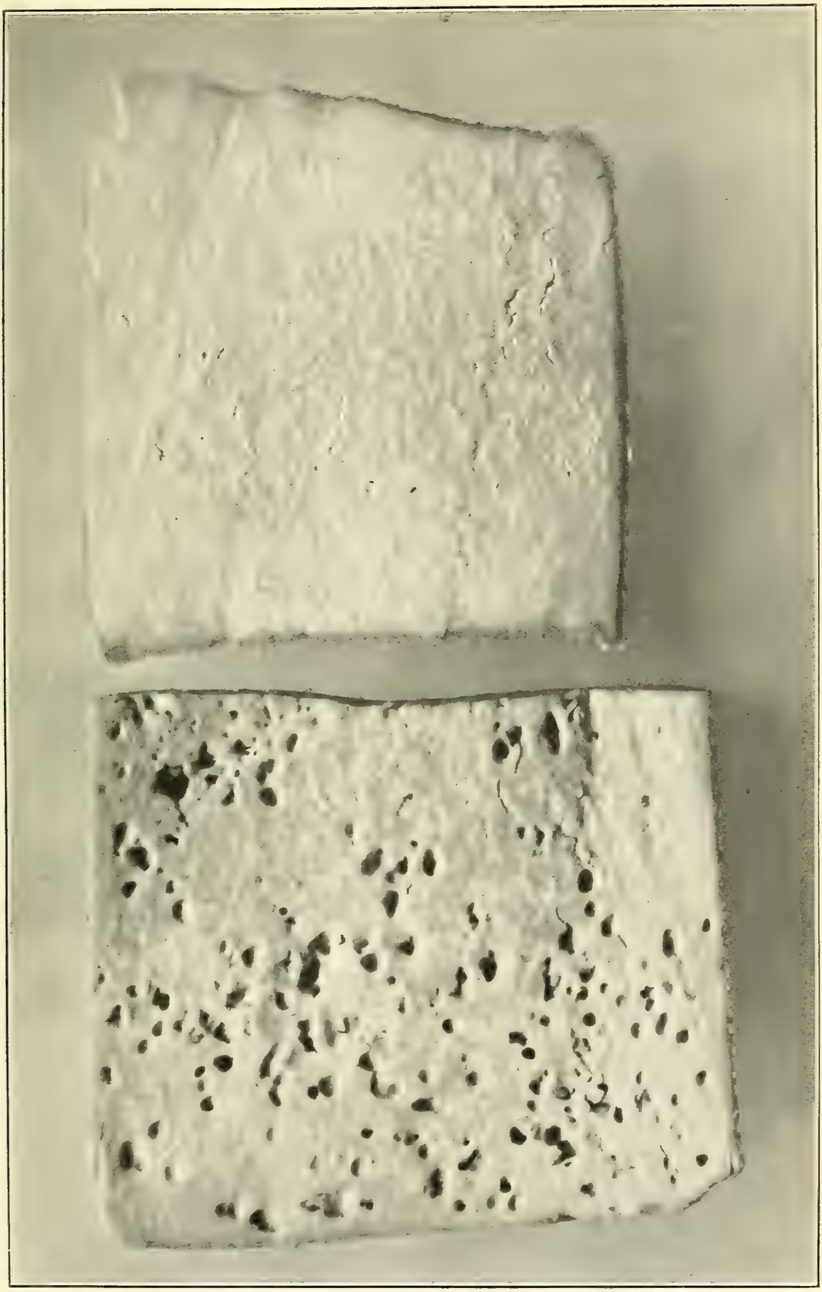
EXPERIMENTS WITH BACILLUS BULGARICUS STARTERS IN A COMMERCIAL FACTORY.

The results of our experiments led us to believe that we could demonstrate two points: First, that it was possible to overcome the faults of milk usually delivered to Swiss-cheese factories early in the spring; and, second, that it was possible to secure a normal eye growth with attending characteristic flavors by the use of cultures adapted for that purpose in cheese made early in the spring and in cheese made once a day instead of twice a day, as is the usual custom in summer. In order to study the use of *Bacillus bulgaricus* starters in a commercial factory, one of the authors spent two weeks, beginning the last week in April, 1913, in a factory where cheaper products (brick and Limburger cheese) were made early in the spring, or until the weather conditions became favorable for the making of good Swiss cheese. The value of these cultures should have been demonstrated earlier in the spring, but the factory did not receive milk enough to make one cheese a day until about May 1. The result of this work is compiled in Table 4.

TABLE 4.—*Results obtained with Bacillus bulgaricus starters in suppressing gas formation in Swiss cheese under commercial conditions.*

Date.	Cheese No.	Starter.		Condition of cheese.
		Amount.	Acidity.	
		Per cent.	*Per cent.*	
May 1	1	1	1.0	Nissler.
2	2	1.5	.7	Do.
3	3	1.5	.9	Do.
4	4	1.5	.9	Do.
5	5	1.5	.8	Do.
6	6	1	.9	Do.
7	7	1	.6	Do.
8	8	1.25	1.0	Good.
9	9	1.25	1.1	Do.
10	10	1	1.5	Do.
11	11	1.25	1.2	Do.
12	12	1.5	1.1	Do.
13	13	1.5	1.4	Do.
14	14	1.25	.9	Do.

The starters used were prepared from pure cultures of *Bacillus bulgaricus* from the laboratory of the Dairy Division at Washington. As the temperatures were rather low at this time it was necessary to



EFFECT OF USING BACILLUS BULGARICUS STARTERS TO CONTROL FERMENTATIONS IN MAKING SWISS CHEESE.

These cheeses were cut 24 hours after making from the same lot of badly contaminated milk; the upper was made with starter, the lower, without any starter, is badly "nissler."

provide some means of keeping the starters at a temperature high enough to insure the growth of the *B. bulgaricus*. A well-insulated box was made for this, somewhat on the order of a fireless cooker, which maintained temperatures very satisfactorily on nights when the outdoor temperature was below freezing. Considerable difficulty with yeasts was experienced, making frequent changes of cultures necessary, as noted on another page. The first six cheeses in Table 4 turned out "nissler," which is an indication of undesirable gas formation. In all the experiments except No. 14 the cheese was made once a day, using a mixture of morning and evening milks. The farmers made no pretense of cooling the milk, and as a very large can holding about 200 pounds of milk is used, the large bulk of milk cooled very slowly, even on frosty nights. The night milk with this treatment had developed so much acid, or such a growth of lactic-acid organisms, that in one instance the whey contained 0.19 per cent of acid at the time the curd was dipped, whereas it should have contained normally but 0.12 per cent. In all cases there was a marked development of acid. From the results shown in Table 3, where the sour-milk starter designated in the table as SM was used in a commercial factory, it would appear that a high development of acidity in the milk from the growth of ordinary lactic-acid formers tends to give a "nissler" cheese. Apparently the milk must be sweet when delivered or the *B. bulgaricus* starters do not suppress all undesirable gas formers.

When it was found to be impossible in the short time at our command to induce the farmers to cool their evening milk, they were asked to deliver twice a day, as is the custom in the summer months. The night milk was then cooled in a kettle by means of a coil through which cold water was pumped. But as the temperature of the cooled milk was not lower than about 68° F., it could not be said that the milk was unusually well cared for. Beginning with experiment No. 7, for which the night milk was cooled at the factory, we had milk sweet enough to work up in a normal manner, and the cheeses were all perfectly free from undesirable gas formation.

The milk delivered generally to the factory was not of the best quality. The brick cheese made before these experiments was badly gassy, and fermentation tests made with the milk of individual patrons at short intervals during the experiments showed that more than one-half of the patrons delivered gassy milk, some of the samples being very bad. It appeared that the starters were of great assistance in overcoming serious trouble with the gassy milk. Ordinarily this factory would not have begun to make Swiss cheese for a month later than it was made successfully in these experiments, though the higher price of Swiss cheese is a great inducement to make this variety rather than brick cheese.

It is worthy of note in this connection that the good cheeses of this series, with one exception, developed very large, though too many, eyes; in fact, the cheeses were hurried to cold storage to prevent cracking from an excessive growth of eyes. No other cheese made at the factory the same season had a sufficient eye development, and no factory is able to secure a satisfactory eye growth so early in the season as this work was done. The unusual development of eyes in the cheese made in this experiment was secured only by the use of the cultures. The culture in this case was obtained from one of our own winter-made cheeses that would rival any imported in eyes, texture, and flavor. It was ground up and incubated in whey for 24 hours. In these experiments unusually heavy cheese starters were used, which possibly accounts for too great a growth of eyes. The cheese made in this factory, after the experiments were completed and when the culture was not used, did not in any case show a satisfactory growth of eyes. Some cultures of *Bacillus bulgaricus* favor the growth of eyes more than others, but the use of starters for securing eyes in Swiss cheese will be discussed in a subsequent paper.

From the results of the experiments with *Bacillus bulgaricus* cultures it would appear that with their proper use in starters, Swiss cheese can be made in winter as well as in summer. It also seems practicable to make cheese once a day. However, *B. bulgaricus* cultures will not be a "cure-all" for any condition of milk which careless farmers may be able to bring about, but if the milk receives as good care as it receives when the best quality of cheese is made at the present time, and the evening milk is cooled at once after milking so it will not have developed acid when delivered to the factory, there should be no serious difficulty with the help of a good starter in making good Swiss cheese once a day and every day in the year.

AMOUNT OF STARTER TO USE.

We have found that 3 per cent of starter can be used without any indication of harmful results in the ripening cheese. Probably a greater amount of a weak culture or of a starter with a low acid content at the time of use could be employed. But 3 per cent of a strong culture with a high development of acid in the starter is apparently all that it is safe to use. More than 3 per cent of starter has in some instances apparently suppressed all tendency to form eyes, while the use of as much as 3 per cent has no apparent injurious effect on eyes, texture, or flavor. With a strong, active culture of *Bacillus bulgaricus*, 2 per cent of starter would undoubtedly prove more than sufficient to insure a perfectly solid cheese, excepting under the most extreme conditions of a poor milk supply. It is suggested that this amount be used, since it can be safely employed.

HOW TO SECURE CULTURES.

The problem of securing cultures of *Bacillus bulgaricus* for making starters will, of course, be an important one. It would be desirable to have a commercial source from which the active, pure cultures could be obtained, but it will probably be some time before cultures can be obtained in this way. In the meanwhile a number of sources are open. Cheesemakers have, in fact, been using *B. bulgaricus* starters unconsciously, which indicates that this bacterium is ordinarily present in the milk or whey of all factories. This can be verified by allowing a sample of whey to stand for about 48 hours at 100° F. If an active culture of bulgaricus is present the whey will become so sour that it can early be detected by smell. It will be best, however, for the cheesemaker to provide himself with an acidimeter outfit to test the strength of the culture. This apparatus is simple, easy to operate, and can be obtained for less than $5. Its cost may be saved on one cheese by insuring a good starter, and it can be used to advantage to find new cultures of bulgaricus. Unfortunately, although *B. bulgaricus* seems to be present almost uniformly in the whey in Swiss-cheese factories, it sometimes becomes suppressed, and under these conditions the rennet putrefies and may cause serious trouble in the cheese.

The *B. bulgaricus* organism is especially likely to be absent entirely or lost in the early spring or late fall under present conditions. This condition has been noted by many European writers who have published discussions on the comparative merits of pure cultures of *B. bulgaricus* and commercial acid (which goes under the commercial name of casol) for insuring a whey rennet that will be free from undesirable gas formers. But there need be no trouble from this source when an active culture of bulgaricus is present and proper temperatures are used. When the temperature conditions are not favorable for the growth of *B. bulgaricus* other types of bacteria may crowd it out, or it will develop so slowly as to have no effect. This accounts in a large measure, probably, for the poor results with Swiss cheese in the colder seasons and for the fact that even in Switzerland great difficulty is experienced in making good cheese in winter.

A good culture of *B. bulgaricus* should be able to produce a maximum of at least 1.5 per cent of acid in whey when carried 48 hours at 100° F., with an inoculation of less than 1 per cent. In our experience it was not difficult to find *B. bulgaricus* cultures that gave an acidity in whey of over 1 per cent in 24 hours carried at 100° F. However, it has been found necessary in the laboratory to change occasionally, as the cultures apparently become weakened.

When cheesemakers either lose their cultures or find by the use of the acidimeter that their cultures have become weakened, a number of ways are open to renew or secure more active ones. Securing samples of whey from factories has proved to be the most satisfactory way of renewing cultures. This would be an easy method for a cheesemaker to follow. The Dairy Division often has samples of whey sent from Wisconsin factories, and will send out a limited number of the most active bulgaricus cultures to those who are equipped to use them and will report the results of their trials. Another way would be to set individual samples of milk from patrons at the proper temperature (about 100° F.) for five days and select the one that developed the greatest acidity. Still another way is to grind up a piece of Swiss cheese in whey and carry at a temperature of 100° F. for five days. We have used this last plan on different occasions, but it is open to two objections. The *B. bulgaricus* may lose its activity by being carried in the cheese. Again, in preparing a starter in this way the bacteria responsible for the eyes in the cheese grow with the *B. bulgaricus*, and the result is a cheese with a decided tendency to form too many eyes. This can in a measure be overcome by allowing the acidity to develop to a high point, which, judging from some of our results, kills the bacteria which form the eyes.

In all the work reported here whey was used in preference to milk for making the starter. It does not develop so high an acidity, but it has two advantages which are very desirable in cheesemaking. A milk starter contains casein coagulated with acid and therefore contains a large part of the living bacteria which do not become thoroughly distributed throughout the milk. Whey has neither of these faults. It is possible also that whey would make a more satisfactory starter for other purposes, though it might not furnish all the qualities desirable in butter-making.

KEEPING THE CULTURE AND STARTERS.

Since *Bacillus bulgaricus* requires a temperature of about 100° F. for rapid growth, the proper conditions are not hard to obtain in summer, and have been supplied to cheesemakers as a rule in their method of carrying their rennet, where the warm whey containing the rennet is set above the fireplace or boiler, and as a result the bulgaricus grows rapidly and provides a good starter. At other seasons some extra means must be provided to insure the right temperature throughout the period required for the starter to attain a sufficiently high acidity. Perhaps as simple a method as any would be a fireless cooker or a well-insulated box of any kind. A square box insulated with granulated cork and with a receptacle for holding the whey which just fitted the inside of the box proved satisfactory for our work. If a fireless cooker is used the plates or stones sometimes placed in them for maintaining heat must be at the proper temperature and would have to be used with the greatest care or the starter would be heated too high and sterilized. In any case it would be desirable to warm up the starter twice a day.

At the present time the cheesemakers take whey for the rennet direct from the kettles, usually before the curd is cooked. The starter could be taken in the same way, though it would probably be better to take out this whey after the curd is dipped. The temperature used for heating the curd has no harmful effect on the *B. bulgaricus* while it checks temporarily the growth of most other organisms, probably including yeasts. This is permissible for carrying starters, though some writers have advised sterilizing the whey, which should not be done unless a mother starter is used for reinoculating. A putrefied rennet would be the certain result. Some have advised the use of rennet extract if the cheese shows any signs of abnormal gas formation. This might help if the gassy cheese were due to the loss of the bulgaricus culture, but as a general rule it would do more harm than good, for if the bulgaricus were present the use of a greater quantity of the whey would provide a better remedy.

Cheesemakers would probably insure themselves against occasional trouble from undesirable fermentation if they would set the whey at the usual temperature 24 hours before adding the dried rennet. This would give the *B. bulgaricus* present a chance to get a good start ahead of any putrefactive bacteria which might be carried by the rennet.

TROUBLE FROM YEAST.

Usually it would be desirable to carry a mother starter, or culture, in a separate vessel, the mother starter being the name given to the small starter carried over from day to day for inoculating the main starter. It is necessary to carry this mother starter so that it will not become contaminated with yeast, which is apparently the only foe of the cheesemaker that *Bacillus bulgaricus* starters will not help to control. All other contaminations of the starter were held in complete subjection by the *B. bulgaricus*. At the factory where our experiments were made the contamination from yeasts was very serious; although all vessels used were sterilized and the whey starter was boiled, the yeast on one occasion spoiled the starter. The conditions in cheese factories seem to be favorable for the growth of yeasts; the air probably contains large numbers of yeast cells.

A MOTHER-STARTER CAN.

To overcome the difficulty from yeast contamination some means are necessary to insure a pure mother-starter which is protected from contact with the air after sterilizing. A can or receptacle which works very satisfactorily was devised by one of the authors (see text fig. 1). This starter-can consists of two tanks (5) and (11) connected by a block-tin collar (7)—brass can not be used, as it prevents growth of the culture. In this collar is fitted a tinned plug (8), fastened to a tinned-brass pipe (6). A brass collar (1) large enough to let the block-tin plug pass through is fastened at the top of the upper tank. Into this brass collar is fitted a brass plug (2), through which passes the tinned-brass pipe (6). Both the pipe and plug are threaded to permit the raising and lowering of the block-tin plug (8) between the two tanks without raising the brass plug in the top tank. When both plugs are in place there should be an opening in the pipe at the point (4) to permit the air to pass from the lower tank (11) to the upper tank (5) when the whey is passing from the upper tank to the lower tank. The end of the brass pipe (6) extending above the upper tank should be plugged with cotton to prevent any outside contamination when the starter is drawn from the lower tank. The opening (3) in the top of the upper tank for filling is plugged with a cork into which is fitted a thermometer. The pipe (12) for draining off the starter is placed about one-half inch from the bottom of the lower tank. This always leaves enough starter for reinoculation. The lower can is insulated with a zinc jacket filled with ground cork (9).

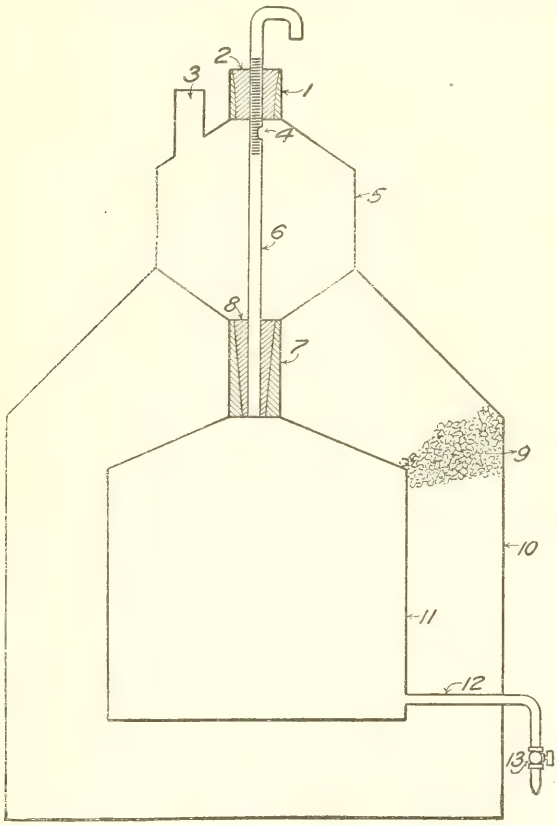


FIG. 1.—A mother-starter can for carrying pure cultures. Although it was designed especially to prevent cultures of Bacillus bulgaricus from yeast contamination in making Swiss cheese, it can be used for all whey cultures.

PREPARING THE STARTER.

The starter can is first sterilized with steam or boiling water. The pure culture is then placed in the lower tank and the block-tin plug screwed down in place. The upper tank is then filled with boiling whey and the cork and thermometer inserted. The whey is allowed to stand in the upper tank until cooled to about 104°F. if *Bacillus bulgaricus* starter is used (in case the common lactic-acid type is used, the temperature should be 77° F.). The block-tin plug is then raised by means of the brass pipe to let the whey pass to the lower tank, where it is inoculated with the bacteria in the pure culture previously placed there. The block-tin plug is then replaced. The next day this starter is drawn off and the upper tank refilled with boiling whey, this operation being repeated from day to day. It is desirable to fill the upper chamber with the boiling whey in order that the chamber may be completely sterilized and all yeast cells destroyed. Milk can not be used in this apparatus, because the coagulated casein might clog the small pipe at the bottom of the lower chamber.

It would appear probable that the starter-can described above might be used for carrying mother starters for all dairy purposes, if whey is used. It could be made in any size to suit, and it might be used for carrying the entire starter. Where used for a mother starter in a Swiss-cheese factory, the upper chamber should hold almost a pint and the lower chamber 1½ pints. If it is used for carrying the entire starter, the upper chamber should hold 5 gallons and the lower chamber slightly more. For a Cheddar-cheese factory a can three times as large as for a Swiss-cheese factory might be needed. As already indicated, the mother starter for which the can is designed is a small starter carried under conditions to insure its remaining pure. The mother starter is added to the larger starter intended for the milk.

To prepare the starter where this mother-starter can is used the whey used should be first heated by setting in boiling water and holding for not less than 15 minutes at about 200° F. It should then be cooled to 100° F. and 2 to 5 per cent of the mother starter added. The whey with the rennet added should then be carried at 100° F. for 24 hours, when it should have more than 1 per cent of acid. If the mother starter becomes contaminated with yeast, which may happen if whey from some other factory or any other means than a pure culture is used to renew the starter, the can should be drained and filled with boiling water two or three times successively to kill the yeast present and another start made with the culture or the whey, as the case may be.

A growth of *Mycoderma*, which shows itself on the starter as a thin white film, is desirable for improving the efficiency of the starter.

This could be grown in the mother starter, and if the whey mother starter is drawn to the level of the tube in the starter-can it will carry enough of the *Mycoderma* to inoculate the starter.

SUMMARY AND CONCLUSIONS.

Many cultures of *Bacillus bulgaricus* obtained from different sources were used as starters in experiments for suppressing gas-forming bacteria in milk used for making Swiss cheese.

The ability to suppress undesirable fermentations was found to vary widely with different strains of *B. bulgaricus*. Several were able to prevent gas formation when the starter was less than 2 per cent of the total amount of milk used. Other cultures did not prove efficient with less than 4 per cent.

Ordinary lactic-acid cultures were not successful in preventing gas formation.

The application of the use of *B. bulgaricus* as a starter was tried in a cheese factory under commercial conditions. Good cheese was made at a season when it was not possible to make marketable Swiss cheese without the use of the cultures.

The results of these experiments indicate that the maker of Swiss cheese can control the fermentations with some cultures of *B. bulgaricus;* that a good quality of Swiss cheese can be made in winter as well as in summer; and that it is probably practicable to make cheese once a day instead of twice a day, as has been necessary in the past.

Methods are described for preparing and keeping cultures. A new type of starter-can for carrying starter is illustrated and described. This starter-can may be used for other dairy purposes with whey starters.

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No. 149

Contribution from the Bureau of Soils, Milton Whitney, Chief.
December 11, 1914.

THE USE OF RADIOACTIVE SUBSTANCES AS FERTILIZERS.

By William H. Ross,
Scientist in Soil Laboratory Investigations.

INTRODUCTION.

A fertilizer may be conveniently defined as any commercial material which, when added to a soil that has been brought into suitable condition for the growth of plants, produces an increased yield in crop production. In producing this result a fertilizer may act in various ways, bringing about an improvement in the chemical, physical, or biological condition of the soil, and generally in all of these. An improvement in all these three classes of soil conditions may also be brought about by other farm operations, as by tillage, green manuring, and the rotation of crops. To what extent these latter operations should be supplemented, or even in a measure replaced, by the use of fertilizers so as to lead to the most profitable returns, is a matter which has given rise to a great deal of controversy, and there still remain considerable differences of opinion on the subject. This is due in a large measure to the fact that the results obtained from experiments carried on locally and under special conditions of farming are often quoted as applying to the whole country, and to conditions of farming of an entirely different type. It is quite evident, however, that any set rules governing the use of fertilizers in farm practice are only applicable when all conditions of soil fertility, climate, cultivation, and crop production are about the same. Fertilizers must therefore be used differently under different conditions, and it is universally admitted that when intelligently applied, where the conditions warrant it, the use of the proper fertilizer brings profitable returns.

A great many forms of fertilizers are used, but all those commercial products which are recognized as of value in the fertilizer trade have the common feature of containing one or more of the

NOTE.—This bulletin discusses the fertilizer value of radioactive materials; it is suitable for distribution in any part of the United States.

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elements—nitrogen, potassium, phosphorus, and calcium. These elements are therefore spoken of as fertilizing elements.

It is further recognized that in a very general way the value of a material is proportional to the percentage of the fertilizing constituent or constituents present in soluble form. Because of its wide distribution, calcium can usually be obtained locally, and consequently it does not enter into the fertilizer trade in the same sense as the other fertilizing elements. To each of the three remaining elements is given by common consent and as a trade practice a definite value per unit, which varies with the form in which the element occurs; the price set on a standard fertilizer, while thus in a sense an arbitrary one, is nevertheless determined in a scientific way by multiplying the percentages of the constituents present by their prices per unit and adding the products.

If nitrogen, potash, and phosphoric acid are absent, the fertilizing value of the material as calculated in this way will be zero; and no material, with the exception of certain calcium compounds, as lime and gypsum, that does not contain one or more of the constituents referred to is recognized at present by agricultural scientists as having commercial value as a fertilizing agent for general farming.

Notwithstanding these facts there have frequently been placed on the market from time to time various so-called fertilizers which contain little or none of the recognized fertilizing elements even in an insoluble form. As a rule these materials consist simply of ground rock, usually of volcanic origin, from various sources, and for which an arbitrary price is asked out of all proportion to the value of the small amount of the fertilizing elements which may be present. Some of these materials, although exploited to quite an extent in the past, have later fallen into disfavor and are now no longer used by anyone, but others of more recent development are still being placed on the market under different trade names. One of these new materials, which is known as "radioactive manure," consists of low-grade uranium-radium ores or ores from which the uranium has been extracted, and it is claimed to bring about by virtue of its radioactivity phenomenal increase in crop yields when mixed with barnyard manure and applied to the soil. Within the past few years the use of this material as a fertilizer has been quite extensively advertised in various parts of the world, and accounts have been given in various scientific publications of numerous results which have been obtained in pot and field tests using radioactive material from different sources.

The object of this bulletin is to give a review of these results and likewise an explanation of the property of radioactivity, in order that a conclusion may be reached as to the value of applying radioactive material to the soil.

PROPERTIES OF THE RADIO-ELEMENTS.

The properties of the radio-elements have been investigated by many of the leading scientists of the present day and have consequently been determined with a degree of exactness and completeness which perhaps has never before been equaled in any other branch of science in the same length of time.

The following points with regard to these properties may be enumerated as having bearing on the fertilizing value of radioactive material:

1. An element is said to be radioactive when it has the property of disintegrating or changing into another element. This property of radioactivity as exhibited by radium, which is the best known popularly of the radio-elements, is one which is inherent in the atom. No substance can be radioactive which does not contain an element which would be radioactive if separated from the substance, and, conversely, if a substance contains such an element, it must be radioactive. Some of the radio-elements, like the ordinary elements, do not give off any rays; others give off one kind of rays only; while still others give off two different rays, each of which may differ from the single radiation, thus making altogether three different kinds of rays. No inactive substance can be made radioactive by exposure to any of these rays. The activity of a given quantity of a radioactive element, like uranium or radium, remains unchanged in whatever chemical or physical state it may exist, whether combined in a soluble or insoluble compound, and whether or not it may be mixed with any substance or substances whatsoever. It therefore follows that its activity can not be intensified by mixing with barnyard manure, as is sometimes claimed.

2. Radium is a product of uranium and can not occur in nature in quantity exceeding the amount with which it is in equilibrium with uranium. For this reason the highest concentration of radium which can ever be found in any ore will amount to only one part of radium in 3,460,000 parts of ore. This quantity of radium is so small that if chemical tests alone had been applied neither radium nor any of its products could ever have been identified. There are physical tests, however, which are much more delicate than any chemical tests. Thus, when the spectroscopic test is applied to lithium, an element which according to chemical tests is of very limited distribution, it is found to be almost universally distributed, and in no spring water, for example, does the test fail to reveal its presence. The electroscopic test for radium is even much more delicate than the spectroscopic test just cited, and it thus happens that radium which occurs in soils, for example, in such minute quantities can nevertheless be identified in all soils. If the same delicate test could be applied to all the ordinary elements, it is universally admitted that they, too,

would be found in all soils[1] and in much larger amounts than radium, for the reason that they occur in nature in much larger quantities. The ordinary elements could not have been discovered if this were not the case. Most soils differ but little in their radium content, as must follow from the fact that almost all rocks[2] which do not contain uranium ores contain pretty much the same quantity of radium.

On an average the radium present in an acre-foot of soil amounts to about 3.6 milligrams.[3] The radium present in 1 ton of carnotite ore containing 2 per cent of uranium oxide (U_3O_8) amounts to 5 milligrams. To duplicate the amount of radium in an acre-foot of soil would therefore require about three-fourths of a ton of 2 per cent carnotite ore from which radium has not been extracted, and which brings about $80 a ton wholesale. It is thus quite evident that to increase the radium content of the soil to any great extent by the use of carnotite or any other radium ore is out of the question as an economic proposition.

The chemical properties exhibited by an element in combination depends on whether the element occurs in a soluble or insoluble form. Thus, the addition of a comparatively small amount of a soluble potash salt has a marked effect on the growth of plants, while the corresponding amount of an insoluble potash silicate would have little or no effect so long as it remained insoluble. As already explained, the property of radioactivity does not change in this way with the form of combination and a given weight of radium in the soil has exactly the same activity as the same weight of radium in any other form of combination that can be added. The argument, therefore, can not be advanced that the radium in radioactive manure is in a more active form than that already present in the soil.

3. When a preparation of radium which has been freed from its products is allowed to stand for a time, the products are again formed and finally reach a state of equilibrium with the radium. When this is the case, the material has its greatest activity, and any preparation which is allowed to stand for a time always consists of a mixture of radium and its products. The first of the products to be formed from radium is a gas called radium emanation. Since radium itself gives off rays, while radium emanation is a product of radium, the activity of radium emanation in equilibrium with its products must always be less than that of radium in equilibrium with its products. It therefore follows that no preparation of radium emanation can be obtained which is more active than the radium available.

When the radium emanation is removed from a preparation of radium, the total radiation evolved from the two sources remains the

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[1] The presence of the rare earths and other rare elements in all soils examined has been demonstrated by W. O. Robinson of the Bureau of Soils. Bul. 122, U. S. Dept. Agr.

[2] Strutt, Proc. Roy. Soc. Lond., (A) 77, 472 (1906).

[3] Moore, J. Ind. Eng. Chem., 6, 373 (1914).

same as that given off from the preparation before the separation. The total radiation has thus not been either increased or decreased by the treatment, and as far as the use of the rays is concerned it must necessarily be just as expensive, although possibly at times more convenient, to treat plants with radium emanation as with the radiation from the equilibrium amount of radium.

THE INFLUENCE OF RADIOACTIVE RAYS ON PLANTS.

Every physical agent known when exceeding a certain minimum intensity is able to affect in a marked degree the germination of seeds and the growth of plants. It would therefore be expected that the rays from radioactive substances, when present in sufficient intensity, would likewise have an influence on plant growth. A great many experiments have been made along this line, and the literature on the subject is already very extensive. Unfortunately in many of the experiments which have been made, no mention is made of the amount of radioactive material used nor of the intensity of the radiations emitted by it. Consequently such experiments can not be duplicated by others, and the results reported are therefore of little value, for it could have been predicted that a very intense radiation would have an injurious effect on plant growth, while radiations of moderate intensity might exert a beneficial effect. Furthermore, owing to an insufficient knowledge of the properties of radioactive rays, many experiments have been carried out in such a way that the effects which were attributed to the rays could not possibly have been due to this influence.

The most extensive experiments in this field which have been described in this country were carried out by Gager[1] at the New York Botanical Garden. In one set of pot experiments a quantity of polonium (activity not given) inclosed in a sealed glass tube was inserted in the soil at the center of the pot, with the end containing the radioactive material about 10 millimeters below the surface. Twelve grains of wheat were then planted without soaking in the soil around the tube. Three other pots were also prepared in the same way with the same number of wheat grains; in one of the pots was placed a tube containing 10 milligrams of radium bromide of 1,800,000 activity; in another, a tube containing 10 milligrams of radium bromide of 1,500,000 activity, while the remaining pot was used as a control. On the fourth day measurements were made of the height of the seedlings, and it was found that the average growth was greatest in the pot containing the polonium and least in the control pot. It is known, however, that polonium gives off alpha rays only, and that these rays are so lacking in penetrating power that they could not

[1] Effects of the Rays of Radium on Plants, Memoirs of the N. Y. Botanical Garden, vol. 4 (1908).

have penetrated the walls of the glass tube[1] in which the polonium was contained, much less could they have penetrated the intervening soil which separated the tube from the planted seeds. If the experiments were carried out as described, the seeds in the pot containing the polonium tube must have been as free from any radioactive influence as those in the control pot, and the marked increase noted in the growth of the seedlings in this pot could not have been due to the presence of the polonium tube as claimed by the author, but must be attributed to some other influence.

From the way in which other experiments were carried out it seems reasonable to suppose that other results were likewise incorrectly attributed to radioactive influence. Thus it was concluded "that freshly fallen rain water tends to retard the growth of roots of beans (*Lupinus albus*) and that the effect is due to the radioactivity of the water."[2] It was further observed from other experiments that "the growth in length of radicles of *Lupinus albus* is uniformly accelerated in an atmosphere containing radium emanation."[3] The intensity of the radiation was not given in either case, but it was indicated, and it is undoubtedly a fact, that the intensity of the radiation in the latter experiment was much greater than in the former. It would thus seem that as measured by the growth that takes place without any radioactive influence, a weak radiation retards, while a stronger radiation stimulates the growth of certain seedlings. This is contrary to experience and to the general conclusion reached by the author that "the rays of radium act as a stimulus to protoplasm. Retardation of growth following an exposure to the rays is an expression of overstimulation. Acceleration of growth indicates stimulation between a minimum and an optimum point."

Experiments were also described in which seeds and seedlings were exposed in a 6-inch pot to the radiation from 10 milligrams of radium bromide of activity 1,800,000. A preparation of 0.5 gram of radium bromide of activity 10,000 was also used. Both retarding and stimulating effects were observed, depending on the seedlings used and the conditions of the experiments. It would be expected that with a radiation of the intensity given by these preparations a marked effect would result, as was observed. The experiments are thus of scientific interest, but they do not give any indication that radium can be of any practical value in general farming. To duplicate the experiments on a large scale would require a quantity of radium which is not available.

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[1] In this connection the author himself states: "I am unable to explain how physiological effects can be obtained with radio-tellurium [polonium] in a sealed glass tube, for this substance gives off only α rays, and these are not thought to be able to pass through the glass walls of the tube. The results, however, were constant and decided, leaving not the slightest doubt as to the physiological efficacy of the preparation." Loc. cit., p. 144.

[2] Loc. cit., p. 178.

[3] Loc. cit., p. 156.

Many experiments on the influence of radioactive matter on plant growth have also been made by Stoklasa.[1] In one set of experiments there was observed the effect of adding varying amounts of uranium in the form of uranium nitrate to a given quantity of soil. Using plants of clover (*Melilotus albus*) a maximum increase in growth of 24 per cent was obtained when 1 part of uranium was used to 1,310,000 parts of soil. But the presence of lead in the form of lead nitrate was found to be even more stimulating in its action since a corresponding increase in growth was obtained with a concentration only one-eighth as great as the quantity of uranium which gave best results. Lead, however, is a rayless element and the effects observed with it must have therefore been due to its chemical properties. As a soluble salt of uranium had to be used to give the effects observed, it is reasonable to conclude that these effects are likewise due, in a large measure at least, to the chemical properties of the uranium rather than to its radioactive properties. Further evidence of the truth of this statement will be given later.

In other experiments Stoklasa[2] made a study of the change in rate of nitrogen fixation brought about by bacteria (*azotobacter chroococcum*) when cultures of these bacteria were placed in an atmosphere containing radium emanation. In carrying out the experiments 2 liters of air having an activity of 150 Mache units[3] were passed daily into the vessel containing the cultures and there resulted from this treatment a marked increase in the amount of nitrogen fixed by the bacteria. It was further observed that the time of germination of seeds was shortened and an increase in the development of plants resulted when watered with water having an activity of from 30 to 2,000 Mache units.

Using a concentration of emanation about 30 times as great as that given by Stoklasa, Fabre[4] likewise observed favorable results in the germination and growth of seedlings. Many experiments on the influence of radioactive matter on plants have also been made by other investigators, but unlike the results just cited the effects reported in the majority of cases were deleterious rather than beneficial.

As radium emanation is an inert gas, the results obtained with its use can not be due to its chemical properties, as in the case of uranium, but must be attributed to its property of being radioactive. It is thus necessary to conclude that radioactive material does have an effect on plant growth, and that when a certain concentration,

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[1] Compt. rend., **155**, 1096 (1912); **156**, 153 (1913); **157**, 879, 1082 (1913).

[2] Loc. cit.

[3] The unit now generally used for expressing a quantity of radium emanation is called the *curie*, or the *microcurie*, and is the amount of emanation in equilibrium with 1 gram, or 1 microgram, of radium. One microcurie per liter equals a concentration of about 2,700 Mache units.

[4] Compt. rend. soc. biol., **70**, 187 (1911).

but not too great a concentration, is used stimulating effects are to be expected in some cases at least. In fact it is to be expected, although not yet clearly demonstrated, that in greenhouse practice and in botanical research, where the results obtained might justify the expense involved, the radio-elements may prove of very great value, as they have done in other branches of science. When consideration, however, is taken of the scarcity of these elements, it does not follow from any experiment so far described that such elements can have any practical application as a fertilizer in general farming. To increase the activity of the atmosphere above the soil with radium emanation would not be feasible in field practice, neither would it be practical to add such a quantity of radioactive material to the soil that the emanation in the underground air would be increased to even the very low concentration used in Stoklasa's experiments, and the same may be said with regard to making irrigating water radioactive.

COMPOSITION OF RADIOACTIVE MANURE.

The source of the so-called radioactive manures consists of the residual rock from which carnotite or other uranium ores have been extracted; or of uranium ores which contain too low a percentage of uranium to make it profitable to extract the radium. Since an ore containing as low as 2 per cent of uranium oxide can be profitably used in the manufacture of radium, it is not to be expected that this percentage of uranium, or its equivalent of radium, will be found in any radioactive manure.

In the following table is given the composition of samples of radioactive materials which have been applied as a manure.

Analyses of samples of radioactive manure.

Constituent.	A	B	Constituent.	A	B
Silica (SiO_2)	80.44	85.90	Phosphoric anhydride (P_2O_5)	....	Trace.
Oxide of iron and alumina ($Fe_2O_3+Al_2O_3$)	2.20	8.65	"Soluble phosphoric acid"	1.37	....
Lime (CaO)	....	.91	"Water, volatile organic matter"	10.54	0.93
Magnesia (MgO)	....	.95	"Soluble salts, soluble free acids"	3.32	....
Soda (Na_2O)	....	.50	Uranium (U)	Trace.	1.00
Potash (K_2O)	....	1.04			
Sulphide (S)	....	.16			
"Sulphuric acid"	5.40	....	Activity	.03 U	.037U

A. Radioactive manure. Analysis according to Foulkes, Bul. Bureau Agricultural Intelligence and of Plant Diseases, 3, 1112. This apparently represents ore from which the uranium has been extracted. The acidity of the material was equivalent to 65 grams of sulphuric acid per kilogram.

B. Radioactive manure. Analysis by author. This material represented the original ore and therefore did not contain any free acid.

FIELD TESTS WITH RADIOACTIVE MANURE.

Field tests with radioactive manure (A in table) have been made by Foulkes[1] in England. The material used contained only a trace of uranium, but had an activity equal to 0.03 times that of uranium.

[1] Bul. Bureau of Agricultural Intelligence and of Plant Diseases, 3, 1111 (1912).

This was mixed with commercial fertilizers in the following proportions: Steamed bone, 20 parts; superphosphate, 15 parts; kainit, 10 parts; nitrate of soda, 5 parts; and radioactive manure, 1 part. One plot received an application of this mixture at the rate of 1,020 pounds per acre, and an adjoining plot received the same application, but without the radioactive manure. Both plots were planted to turnips, and when the crop was grown it was found that the yield was greatest in the plot to which the complete fertilizer, plus the radioactive manure, had been added. A similar result was obtained with mangels.

Radioactive material of exactly the same composition as that given by Foulkes was also used by Malpeaux[1] in making pot and field experiments with oats, potatoes, sugar beets, and mangels. The material was mixed with a complete fertilizer made up of sodium nitrate, superphosphate, and potassium sulphate to the extent of 5 per cent and applied at the rate of 22 to 44 pounds per acre. In the case of oats, sugar beets, and mangels, an increased yield of about 15 per cent was obtained on an average on the plots to which complete fertilizer, plus radioactive material, was added, over that obtained from the plots to which complete fertilizer only was added. In the case of potatoes, it was not observed that the radioactive material had any beneficial effect.

A very extensive series of experiments was also carried out by Berthault, Bretigniere, and Berthault,[2] using material for which exactly the same analysis was given as for the radioactive manure used by Foulkes and by Malpeaux. Its effect on a large number of crops (cereals, grasses, and roots) was tested by applying the material alone and when mixed with standard fertilizers. It was found that when the radioactive manure was used alone the positive and negative results were about equal for the total weight of the plants and for stalks and grain, but the negative results were the more numerous for tubers; with superphosphate the results obtained were generally unfavorable, particularly for the grain, but for tubers they were more often favorable; and with complete fertilizer the favorable results were the more numerous for all crops.

It was concluded that while the results obtained were not decisive, they show that radioactive substances were more efficacious in the presence of a complete fertilizer than when used alone, or with phosphate or nitrogenous manures.

It is difficult, however, to understand how this conclusion regarding radioactive substances follows from the experiments described by the authors, in view of the fact that they acknowledge having had the material which they used tested for radioactivity and that none could be detected. It therefore follows that the results obtained,

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[1] Vie Agr. et Rurale, 2, 241 (1913). [2] Ann. Ecole Nat. Agr. Grignon, 3, 1 (1912).

whether of a favorable or unfavorable nature, could not have been due to the radioactivity of the material, but to some other influence.

As shown in the table, the acidity of the material was equivalent to 65 grams of sulphuric acid per kilogram, while the "soluble phosphoric acid" amounted to 1.37 per cent, and the "soluble salts, soluble free acids" amounted to 3.32 per cent. All these constituents when exceeding a certain minimum concentration have a marked effect on plant growth. Notwithstanding this, however, apparently no account was taken of the presence of these constituents in any of the foregoing experiments, but rather all effects observed, whether of a stimulating or retarding nature, were attributed to the exceedingly weak radioactivity of the material, which was claimed to be equal to 0.03 of the activity of uranium, but which at least in the case of the material used by Berthault, Bretigniere, and Berthault, was too small to be detected.

If it is assumed that the material used in these investigations has the radioactivity which was claimed for it, and that this was due to radium and its products, then it can be calculated that in an application of 25 pounds of the material per acre the amount of radium thus applied to an acre would be less than one one-hundredth of the radium already present on an average in an acre-foot of soil. This amount is so small that when uniformly distributed through the first 6 inches of the soil there would be radiated per second from the material added only about 2 alpha particles—that is, 2 atoms—from each pound of soil. Furthermore, of the particles so radiated, only a very small fraction would be able to escape from the particles of material in which they originate. The number of beta particles radiated would be still less than the alpha particles.

The radioactive material (B), of which an analysis is given in the table and which was kindly supplied by a firm in this country, has an activity of 0.037 that of uranium, and is therefore slightly more active than the material referred to above. An application of from 20 to 25 pounds per acre was recommended, mixed with some standard fertilizer, but even in the case where the largest application is used the quantity of radium so applied per acre is only one-fiftieth of the radium already present in an acre-foot of soil. In defense of the use of such a minute quantity of any substance it has been explained that "this material is not a fertilizer, but that it gives to the plant additional power to consume the plant food that is already in the ground or that is put there by artificial means in the form of any brand of fertilizer." The use of the word fertilizer in this statement is no doubt intended to mean a plant food. As already pointed out, however, a material does not necessarily have to act as a plant food to be properly called a fertilizer, for this term is also used with reference to any material which when added to the soil brings about an increase in the growth of crops. If radioactive manure really acts in the way described, it could then be properly called a fertilizer; and, further, if its function is to give to the plant additional power to consume plant food, its effect should be noticed when added to the soil alone as well as when mixed with a standard fertilizer.

Field tests with radioactive mineral from still another source have been made by Ewart,[1] Melbourne University. These tests were made in two different places, in each of which there were selected a series of four plots. In the case of the first series each plot had an area of one-third acre. Plot 1 received 50 pounds of superphosphate per acre; plot 2, 50 pounds of superphosphate and 50 pounds of finely ground radioactive mineral per acre; plot 3, 50 pounds of radioactive mineral per acre; and plot 4 was unmanured. The plots used in the second series had an area of approximately one-fourth acre, and the same applications were made in this case as in the first, with the exception that 59-pound portions of the materials were used instead of 50-pound portions. From the yields obtained it was concluded that "there is no evidence to indicate any beneficial action of the radioactive mineral upon the growth and germination of wheat, when quantities which could be used in agricultural practice are employed. Any stimulating action which it might exercise when first applied, seems, if anything, to be converted into an injurious action when in prolonged contact. There is nothing, therefore, in these results to show that radioactive mineral is of the least benefit to wheat when applied in the same manner as manure."

CATALYTIC FERTILIZERS.

In addition to the experiments which have been described on the use of the radio-elements as fertilizers, many tests have also been made during the last few years of the action on plants of still other elements which are not recognized as essential to the growth of plants. Among the different elements which have been studied in this way may be mentioned copper, nickel, zinc, and lead. These elements are of rare occurrence in the soil, and are ordinarily recognized as plant poisons, but quite remarkable benefits have been obtained by the application to the soil of a very small quantity of a soluble salt of these elements. Plants so treated are said to have been stimulated, and because of the small amount of the material necessary to produce noticeable results, these compounds when used in this way are spoken of as "catalytic fertilizers."

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[1] J. Dept. Agr., Victoria, 10, 417 (1912).

With a concentration of 1 part of lead, as lead nitrate, in 965,000 parts of soil Stoklasa[1] obtained in pot tests with oats (*Avena sativa*) a maximum increase in growth for the grain and straw of 53 per cent over that which took place in the control pot; but on increasing the concentration of the lead only 2.5 times its toxic action became apparent, and a decrease in growth resulted. Similar results were also obtained, as already pointed out, in pot tests with clover using uranium nitrate. With this compound the maximum stimulation was obtained with a concentration of 1 part of uranium in 1,310,000 parts of soil, but as the concentration of the uranium was increased its toxic action became manifest, and the crop yield gradually decreased.

A corresponding series of experiments was also made by Loew and his coworkers[2] using salts of both uranium and thorium. From the results obtained it was concluded that "uranium and thorium compounds differ widely in their effects on plants, uranium salts being highly poisonous, thorium salts not."[3] It is known that thorium and uranium both give off the same rays and of approximately the same intensity. It would be expected, therefore, if the effects which these elements produce on plants are due to their radioactivity, that the effects would be approximately the same for each element. Since this is not the case, and since the results obtained with uranium correspond with those which follow the use of the so-called catalytic fertilizers, it is necessary to conclude that the action of uranium on plants is due to its chemical properties rather than to its property of being radioactive.

The material (B) of which an analysis is given in the table above contains 1 per cent of uranium oxide. An application of this material of about 175 pounds per acre would thus give to the first six inches of the soil a concentration of uranium equal to that which Stoklasa found, in the form of the nitrate, gave greatest stimulation to clover plants. An effect would, therefore, be expected to follow the addition to the soil of finely ground uranium ores, but whether the result will be beneficial or otherwise will depend on the amount applied and the kind of crops grown.

In the various experiments which have been described on the use of radioactive manure no account has apparently been taken of the chemical action of the uranium present, and the conflicting results obtained with radioactive material from different sources are no doubt to be explained by the fact that the radioactivity of the material was alone considered without regard to the presence or

[1] Compt. rend., 156, 153 (1913).
[2] Bul. Coll. Agr., Tokyo Imperial Univ., 5, 173 (1902); 6, 144, 161 (1904).
[3] Ibid, 6, 165.

absence of uranium, or of such nonradioactive constituents as soluble salts and free acids.

The subject of catalytic fertilizers is an interesting one, and worthy of careful investigation, but the manner in which they are able to influence so effectively the growth of plants is as yet but little understood. Until further knowledge is gained along this line, and particularly until it is demonstrated that the application of such materials to the soil will not lead to their accumulation with injurious results, the use of uranium, or of any of the other heavy metals, as a fertilizer in general farming is not to be recommended.

SUMMARY.

Attention is called to a new material which has recently been exploited for use as a fertilizer, and which consists of the residual rock from which uranium has been removed, or of uranium-radium ores of too low grade to be used for the extraction of radium. This material, which is known as "radioactive manure," is claimed by virtue of its activity to have a marked effect on stimulating the growth of plants when mixed with a relatively large amount of standard fertilizers and applied at the rate of 20 to 50 pounds per acre.

When consideration, however, is taken of the facts: (1) That the greatest quantity of radium which can exist in an ore amounts to only 0.00003 per cent; (2) that the intensity of the radium rays is limited by the quantity of radium present; (3) that all rays, like all chemical substances, must exceed in intensity or concentration, a certain limiting value to produce any noticeable results, or any results whatever; (4) that radium costs $120,000 a gram; and (5) that the activity of radium or any other radio-element can not be increased by any treatment whatsoever, but remains unchanged in whatever state of combination it may exist, it seems incredible that radium or any of its products can have any economical application as a fertilizer in general farming; and still less credible that the so-called radioactive manure has any value, as far as its radioactivity is concerned, since the radium already present, on an average, in an acre-foot of soil, is about 100 times greater than is contained in the quantity of radioactive manure commonly recommended for application to an acre.

Many experiments have been made in studying the influence of the radio-elements, when freed from their ores, on the germination of seeds and the growth of plants, and from the results obtained it is to be expected that in botanical research, and possibly in greenhouse practice, where the results obtained may justify the expense involved, the radio-elements may prove of considerable value; but when consideration is taken of the scarcity of these elements it does not follow

from any experiments yet described that such elements can have any practical application as a fertilizer in general farming.

Evidence is given to show that the action of uranium on plants is due to its chemical properties rather than to its property of being radioactive, and that the conflicting results obtained with radioactive manure from different sources is to be explained largely by the presence of uranium, and of such nonradioactive constituents as soluble salts and free acids.

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BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 150

Contribution from the Bureau of Soils, Milton S. Whitney, Chief.
January 23, 1915.

UTILIZATION OF THE FISH WASTE OF THE PACIFIC COAST FOR THE MANUFACTURE OF FERTILIZER.

By J. W. Turrentine,
Scientist in Soil Laboratory Investigations.

CONTENTS.

INTRODUCTION.

In pursuance of the investigation by the Bureau of Soils of the fertilizer resources of the United States, the fisheries of the Pacific coast, particularly the salmon-canning industry, were examined during the summer of 1913 to determine the possibility of developing a source of fertilizer materials in the waste produced in that industry. The purpose of this investigation was (1) to determine the amount of waste and the places where produced, and (2) the possibilities of its utilization as a source of fertilizer. Obviously, it is of little interest to know the fertilizer resources of the country without knowing how they may be utilized; the possibility of their utilization determines their value as resources. A third aspect was given the investigation by the problem of determining possible ways in which waste fish could be conserved in conjunction with that other vast source of fertilizer materials, now practically untouched, the giant kelps of the Pacific coast.

Note.—This bulletin discusses the utilization of fish waste in the salmon-canning and similar industries on the Pacific coast as a source of fertilizer material.

In a previous report on the Menhaden Fish Fertilizer Industry of the Atlantic coast,[1] the fish-fertilizer resources of the Atlantic coast have been discussed. In the introduction to that report the contributions from this bureau on the subject of fertilizer resources of the Nation are mentioned. Since the completion of that report, Waggaman has reported on the phosphate fields of South Carolina,[2] the utilization of acid and basic slags in the manufacture of fertilizer,[3] and the possible commercial utilization of nelsonite.[4] Free has described the topography of the desert lake areas,[5] while Young has discussed the chemistry of the salines of that region.[6] Crandall has continued his study of the kelps of southern California, and Frye[7] and Rigg,[8] during the summer of 1913, surveyed the kelp groves of southeastern and western Alaska, respectively. Cullen, Lindemuth, Merz, and Parker have studied further the composition of kelps.[9] Cameron has reviewed the sources of potash in the United States.[10] Ross has studied the decomposition of feldspar,[11] and Smith the value of sponges as fertilizer.[12] Gardiner has determined the potash content of certain muds from sugar refineries,[13] and the writer has surveyed the nitrogenous resources of the United States.[14]

Present agricultural practice prescribes the use of three chemical elements as a "soil amendment," a "stimulant for plant growth," or a "plant food," as it is variously put. These three elements when applied to the soil in which a crop is growing have been found by practice to afford an increased crop yield. They are phosphorous, potassium, and nitrogen, spoken of by the respective trade terms of phosphoric acid, potash, and "ammoniates." In the commercial fertilizers phosphoric acid is found in the form of calcium phosphate, which is bone phosphate or rock phosphate, usually treated with sulphuric acid to render it soluble. Potash is found as a salt or salts of potassium, either sulphate or chloride, and the "ammoniates,"

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1 Bul. 2, U. S. Dept. of Agr.

2 Bul. 18, U. S. Dept. of Agr.

3 Bul. 95, U. S. Dept. of Agr.

4 J. Ind. Eng. Chem., 5, No. 9, Sept., 1913.

5 Bul. 54, U. S. Dept. of Agr.

6 Bul. 61, U. S. Dept. of Agr.

7 Rept. 100, U. S. Dept. of Agr., Parts IV and V.

8 Ibid.

9 J. A. Cullen, On the Available Nitrogen Content of Kelp, J. Ind. Eng. Chem., 6, 581 (1914); Merz and Lindemuth, The Leaching of Potash from Freshly Cut Kelp, J. Ind. Eng. Chem., 5, 729 (1913); Merz, On the Composition of Giant Kelps, ibid., 6, 191 (1914); Parker and Lindemuth, Analyses of Certain of the Pacific Coast Kelps, ibid., 5, 287 (1913).

10 Possible Sources of Potash in the United States, Yearbook, U. S. Dept. Agr., 1912, p. 523; Kelp and Other Sources of Potash, J. Frank. Inst., Oct., 1913, p. 347.

11 Decomposition of Feldspar and Its Use in the Fixation of Atmospheric Nitrogen, J. Ind. Eng. Chem., 5, 725 (1913).

12 Sponges as a fertilizer, ibid., 5, 850 (1913).

13 Ibid. 6, 480 (1914).

14 Turrentine, The Nitrogenous Fertilizers Obtainable in the United States, Bul. 37, U. S. Dept. of Agr.

as the inorganic salt of ammonia, ammonium sulphate, the inorganic salts of nitric acid, sodium nitrate, and inorganic compounds of nitrogen, calcium cyanamid, or the organic compounds of nitrogen, contained in animal or vegetable refuse matter, cottonseed meal, abattoir tankage, or fish scrap. The usual commercial fertilizers contain these three elements and have the designation of "complete fertilizers." These are sold under various brand names, the various brands frequently being recommended for particular crops. The proportion of the three essential ingredients is varied; as a usual thing that of the phosphoric acid is considerably higher than the other two, which are present in about the same proportion. Thus, for example, a "6–2–2 mixture" contains 6 per cent phosphoric acid (P_2O_5), 2 per cent ammonia (NH_3), and 2 per cent potash (K_2O). Its selling price in the retail market is based on its analysis. Little attention is paid to the source of these ingredients so long as the essential compounds are "available," or readily may be decomposed or made soluble for the use of the plants.

The Nation's supply of these three common ingredients of fertilizer may be summarized as follows: Of phosphoric acid there is an abundant supply in the large deposits of phosphate rock in Florida and Tennessee, and the enormous deposits of Idaho, Montana, and Wyoming. Of potash, now obtained exclusively from the German mines, there is little known in this country outside of the desiccated residues in Searles Lake, Cal., and the giant kelps of the Pacific littoral. In the latter there is much more than enough to supply the present demands of the fertilizer trade of the United States, the present annual consumption of potash being about 1,250,000 tons, of varied composition. At present the kelps are not supplying any of this, since it has not been determined by actual experimentation on a commercial scale that they can be used economically as a source of potash. Estimates based on costs of similar operations indicate that they can be so used. Of "ammoniates" there is a large source in the ammonia produced as a by-product in the distillation of coal for the production of gas or coke, or both. This source is but partially developed, as by the methods most commonly practiced in this country this possible by-product is not recovered. The amount of ammonia now going to waste is almost large enough to supply all of the "ammoniates" now demanded by the fertilizer trade. The abattoirs supply a large amount of tankage and dried blood of high fertilizer value; but of these possible by-products there is still an enormous loss through the lack of organization and cooperation in the small-scale slaughter of animals for food.

The present consumption of the various "ammoniates" and their relative contribution to the total amount of nitrogen used in the fertilizer industry are shown in the table following.

TABLE I.—*Sources of nitrogen used in mixed fertilizers of the United States. (Figures are approximations.)*

Material.		Amount used in United States.	Nitrogen content.	Nitrogen yielded.
		Tons.	*Per cent.*	*Tons.*
Ammonium sulphate		215,000	19.75	42,463
Sodium nitrate (Chilean)		85,000	15.5	13,175
Calcium cyanamid			18.0	
Cottonseed meal	High	681,000	6.5	44,272
	Low	388,000		24,320
Fish scrap		70,000	9.0	6,300
Tankage	High	162,000	6.5	10,500
	Low	99,000		6,450
Dried blood	High	57,500	11.0	6,300
	Low	37,700		4,150

This report is designed for the information of the layman who is totally unfamiliar with the fish industries of the Pacific coast, of those familiar with the fishing industries but not familiar with the fertilizer trade, and particularly of those who are interested in the manufacture of fertilizer from fish waste. For this reason all phases of the subject are discussed, some of them in such detail as possibly to appear extreme to those familiar with these details. Where such details are omitted from this report, the literature containing them, generally easily accessible Government reports, is referred to where possible. The apparatus for use in rendering fish waste is discussed in greatest detail, because, of all the items conneced with the industry herein proposed and advocated, this is considered the one on which information is most apt to be lacking and therefore most likely to be desired. The writer has been assured of the willingness and the desire of many of the operators of canneries to conserve the by-products now lost as soon as they are informed of the proper methods and apparatus to be used. An especial effort therefore is made to present all available information concerning these, and to discuss fully their advantages and disadvantages.

TECHNOLOGY OF CANNING.

FISHING.

Salmon for use by the canneries are caught in traps or pound nets, purse seines, haul seines, gill nets, and fish wheels. In southeast Alaska the greater portion of the fish are taken in traps, owned and operated by the packers, while in the Puget Sound region many are caught with purse seines and gill nets. On the Columbia River drag seines, gill nets, and fish wheels are in general use.

TRAPS.

The traps or pound nets are designed to intercept the fish as they swim in courses paralleling the shore or passing certain points. For this purpose a "lead" is built, consisting of a line of net or woven wire supported on piles or posts and extending from a height slightly greater than that reached by high water to the bottom. It extends at right angles to the shore outward to a suitable depth.

The fish, in moving along the shore, encounter the "lead" and turn outward toward deep water to pass around the obstruction. To intercept them the trap proper is provided with a V-shaped entrance designed to lead them, as they swim outward, into the trap. This, from its shape, is spoken of as the "heart" of the trap. The outer ends of the two branches of the V are provided with "jiggers," an inward extension of the ends of the limbs of the V, so constructed as to divert back into the "heart" the fish seeking to escape around them. The apex of the first heart enters a smaller and supplementary heart of similar shape, which terminates at its apex in an elongated, constricted portion of its netting, called the "tunnel," and enters the "pot." The "pot" is a cubical compartment, which may be joined on one or both sides, by means of a shorter "tunnel," with the "spiller." The latter receives the captured fish and acts as the receptacle from which they later are unloaded from the trap.

The trap usually is constructed of piles driven into the bottom. These are connected at the top by stringers. Upon the piles and supported by the stringers is stretched the net constituting the walls of the various compartments. The bottom or floor of the heart slopes upward toward the "tunnel." This, by leading the fish swimming near the bottom up into the trap, obviates the necessity of extending the subsequent compartments of the trap entirely to the bottom. These then are built only to a convenient depth; they are floored as well as walled with net.

A later modification of the trap, designed to do away with the expense of driving piles, or for use in locations not suitable for pile driving, is the floating trap. The shape of the floating trap essentially is the same as that of the stationary trap. It is constructed of a staunch framework of logs bolted together, which floats and from which extend sections of iron pipe to support the requisite nets. The lead likewise floats. It is a string of logs beneath which woven wire is stretched between sections of iron pipe supported by the logs. The whole is securely anchored in position.

A trap which is catching fish is said to be "fishing." The captured fish are transferred to a scow for conveyance to the cannery. To load, the scow is made fast to the pilings supporting the "spiller"; or, in the case of the floating trap, to the logs constituting the supporting frame of the "spiller." The "tunnel" from the "pot" to the "spiller" is closed and the walls of the latter are dropped almost to the surface of the water. (See Pl. I, fig. 1.)

The fish are transferred from the trap to the scow by means of the "brailer" (Pl. I, fig. 2), which is a stretch of net perhaps 20 feet long by 10 feet wide. One end is made secure to the side of the scow nearest the trap. To the other end are attached three lines, the central one of which extends through the block at the top of a derrick rigged on a tug drawn alongside and is made fast to the capstan on the deck of the tug. The other two are held in the hands of two operators stationed in a dory within the "spiller" compartment of the fish trap. The "brailer" is weighted at its movable end with an iron rod or section of iron pipe and also by short sections of chain distributed at proper intervals along its edge.

In operation, the line from the capstan on the tug is played out, whereupon the "brailer" falls into the "spiller" and is sunk by its own weights. The two men in the dory then pull upon their lines and straighten out the "brailer" in a horizontal position beneath the mass of fish. At a signal the "brailer" is hoisted to a perpendicular position by the line running to the tug, and the fish lifted by it slide or tumble into the scow, to the side of which the "brailer" is attached. This operation is repeated until the "spiller" is emptied or until the scow is filled. The writer has witnessed the filling of a scow of 30,000 fish capacity within an hour and a quarter.

Perhaps one of the greatest advantages, to the packers, of the fish trap lies in the fact that the fish in the traps are kept in moving water and alive and therefore fresh until they are needed at the cannery. This is of particular advantage in the height of the canning season when fish are abundant and are being received at such a rate as to tax the capacity of the cannery. The fish traps may be drawn upon when fish from the seine fisheries are not immediately available.

PURSE SEINES.

The purse seine, so called because it is provided with a line run through rings at the bottom by which it may be closed as a purse with a draw string, is about 1,000 feet long by 125 to 150 feet in width. Rings of galvanized iron strung along its bottom serve both as weights to keep it stretched and to receive the purse line.

The seine is operated in such manner as to inclose the school of fish, and is then closed at the bottom. To accomplish this, when a school of fish is sighted, one end of the seine is held in a dory while the main length of it is played out from a power boat, which pursues a course encircling the school. When the circle has been completed and the power boat has returned to the dory, the purse line is drawn in by a power winch and the slack in the seine is taken aboard until the fish are forced into a small compass. They are then "brailed" or dipped into the boat, transferred by means of a "gaff," or the mass of fish is drawn aboard while still inclosed in the pursed seine.

HAUL SEINES.

This type of seine may vary in length from 500 to 2,500 feet. In its center is a baglike section, sometimes called the "bunt," which may be about 300 feet in length. Two boats are required to operate the seine, one a dory, which holds the more nearly stationary end of it, and the other a large seine boat, which carries the seine and plays it out in such manner as to encircle the fish. The dory approaches the shore directly, while the seine boat approaches it after completing a wide curve in the water. The seine usually is drawn ashore, most frequently upon a favorably sloping sandbar, by means of horses.

This method of fishing is adapted only to locations where a smooth and gently sloping shore is available, so that the seine can be hauled in promptly and easily before the fish have escaped. It most frequently is seen in use on the Columbia River.

GILL NETS.

The size and shape of gill nets are determined by the characteristics of the body of water in which they are to be used, and the dimensions of the meshes by the size of the salmon to be caught. The net is supported by corks and is kept distended by leads attached to the bottom. It is stationed in the tidal or river current in such manner as to form the letter "L," with the end of the longer branch against the shore and the other flowing loose in the current. As the position of the net is usually maintained by the current without the assistance of stakes, where the current is tidal the net is placed at the beginning of a tide and is taken in before a change in the direction of flow occurs. As the success of this manner of fishing depends on the entanglement of the fish in the meshes of the net, it can be applied only under those conditions whereby the net is rendered invisible to the fish, in muddy water or at night.

At the end of the fishing period the seine is pulled aboard the boat of the attendant, the enmeshed fish being removed as the net is drawn in. The same form of net may be made fast in the stream by stakes or other anchorages and may be allowed to "fish" as long as the attendant sees fit.

Perhaps the greatest objection to this form of fish-taking apparatus lies in the fact that the enmeshed fish are killed, probably immediately, and are permitted to remain suspended in the water for an unknown period. The fact certainly can not be regarded as enhancing the value of the fish, and may render the fish undesirable for food.

FISH WHEELS.

Fish wheels are designed to catch the salmon on their course up the rivers in which the wheels are placed. They are of various dimensions and methods of construction, being built in that shape and size best adapted to their respective locations. In size they vary from about 10 feet to about 30 feet in diameter and in width from about 5 to 15 feet. The wheel is so mounted, either in a permanent structure built out from the shore or upon rocks in midstream, or upon a scow, which can be anchored in the desired situation, that it is submerged partially in the water. The flow of the stream causes the wheel to revolve. "Buckets" of woven wire are built in the wheel in such a manner that as the wheel revolves they pass through the water as scoops, picking up the fish. Frequently series of piles are built extending out into the stream in such a way as to direct the fish into the wheel. Mounted in the axis of the wheel, or in some other suitable manner, is a trough-like receptacle for the fish. This is frequently built so as to empty into a scow. The curve of the scooplike bucket of the wheel is such that as the wheel revolves and the bucket is lifted, the fish in the bucket are made to slide toward the axis and finally to fall into the trough.

This manner of fishing is practically automatic. During the season in which the salmon are moving upstream the method is satisfactory for supplying the demands of the packers. One hears reports of scows being sunk by fish taken during a night's operations.

The catch of salmon in Alaska by the three principal forms of gear—seines, traps, and gill nets—is shown in the following table:[1]

TABLE II.—*Percentage of total catch of salmon by the three principal forms of gear used in Alaska, for the year 1913.*

Apparatus.	Section of Alaska.		
	Southeastern.	Central.	Western.
	Per cent.	*Per cent.*	*Per cent.*
Seines	48	47	2
Traps	50	46	4
Gill nets	2	7	94

UNLOADING.

The salmon are unloaded at the canneries (Pl. II, figs. 1 and 2) by being pitched, generally on two-pronged forks, into an elevator which deposits them upon the floor of the house in which they are to be cleaned. (Pl. III, figs. 1 and 2.) Here they are sorted into grades. As they lie in piles upon the floor streams of fresh water—in Alaska frequently icy cold and of a high degree of purity—are directed upon them.

[1] Bower and Fassett, The Fishery Industry of Alaska in 1913. Pacific Fisherman, **12**, No. 1 (Special), 54 (1914).

FIG. 1.—CAPTIVE SALMON IN THE "SPILLER" OF A TRAP

FIG. 2.—"BRAILING" SALMON FROM A TRAP.

The freshly caught fish are not regarded as being in the best condition for canning. It is said that the flesh is elastic and will not remain compressed in the cans. For this reason it is difficult to put into a can the requisite weight of fish, and many light-weight cans result. Therefore the fish are allowed to lie about 24 hours before being canned. When, as frequently happens, they are hauled long distances, from the trap or seining grounds to the cannery, the length of time they are allowed to remain on the canning floor is brief or negligible. In warm weather, or in a warm climate, to permit the fish to remain unchilled for such a length of time would result in their deterioration. In Alaska at least, where the weather, even in the summer, is much of the time cold and rainy, little detriment probably is caused by their seasoning period of 24 hours, especially where they are kept thoroughly washed in cold weather.

From the floor of the cleaning house the salmon are pitched upon a table by means of "pews" or one-tined forks. (Pl. IV, fig. 1.) This is generally thrust into the head, but frequently into the body, of the fish. Upon this table the fish are arranged in order and passed on to the "butchers."

CANNING.

DRESSING.

Formerly the cleaning or butchering was done by Chinamen, and in some canneries this practice is continued. In most instances, however, cleaning by hand has been supplanted by machine cleaning.

The mechanical cleaner is spoken of in the parlance of the cannery as the "iron chink" (Pl. IV, fig. 2), a name which originated from the pseudo name of its human predecessor. Without entering into a detailed description of this machine, it is sufficient to say that it essentially is a revolving disk or wheel about 2 feet in diameter, around which knives and stiff brushes are arranged. These work together to split the fish along its belly, to remove its viscera, and to sever its fins, and finally its tail.

The machine is fed by two laborers, the first of whom places a fish under a stationary knife, against which it is lifted mechanically. The second laborer thrusts the beheaded fish into a slot, of which there are a number on the peripheral rim of the wheel, tail first, so that it becomes wedged and is held firmly. It thus is lifted and carried around, belly outward, by the wheel, and is brought successively against the knives and brushes. Abundant jets of water are made to play upon the fish as it passes through the machine.

This contrivance works rapidly and fairly successfully, with a rated capacity of 50 fish per minute and an actual output of 36 dressed fish per minute. It thus is possible to do away with the large force of skilled and high-waged dressers. Fish are by no means uniform nor rigid objects; therefore no machine can be expected to adapt itself to the variation in size and the manner in which they pass through the machine. As the fish are not dressed uniformly by the machine, they subsequently must be passed under the knives of the "slimers," laborers whose duty it is to finish the work left incomplete by the machine. As the number of these about equals the number of "butchers" which would be required if the dressing were done altogether by hand, there is not the economy in labor resulting from the use of the mechanical cleaner that would be expected. The fact that much less skill is required of "slimers" than of "butchers," however, is an item greatly in favor of the use of the mechanical cleaner.

CUTTING.

After being thoroughly cleaned, the fish are cut into pieces of convenient size for filling the cans. A mechanical cutter of simple design has been adopted for this purpose. It consists essentially of a short conveyor which is made to revolve over bearings in such a way as to describe an ellipse. Blocks of wood are placed at intervals to carry the fish. At the apex of the ellipse revolving knives are placed. These revolve in horizontal slits in the conveyor and blocks. As the blocks start on their upward course the fish are placed upon them by hand and are carried through the knives. The distance between the knives is such that the fish are cut into sections of the proper length to fill cans of the size for which they are intended.

FILLING THE CANS.

Cans designed to hold a pound of fish are filled usually by a machine which, by means of a plunger, thrusts into the can pieces of salmon already cut to the right length and trims off that which projects. As the thrust of the plunger is uniform, the machine is able to load the cans with a nearly exactly uniform weight of fish, and works rapidly. Less than a second is required in filling a can. From the filler the cans are passed along a table, where they are inspected for short weight. Smaller cans are filled by hand. Their shallowness makes them less adapted to the filling machine, as they do not retain their charge of fish so readily.

After filling, it remains to cap the cans or put the lids on, cook the contained fish, seal, clean, and label. The canning process involving the use of soldered cans has been supplanted almost entirely by that based on the use of the solderless or so-called "sanitary" can. The latter process, being almost entirely automatic, effects a great saving in labor as well as floor space, and is commendable from both a mechanical and a sanitary point of view.

The modern cannery is equipped with machinery in units. A unit is spoken of as a "line." The one-line cannery is equipped with a mechanical cleaner or "iron chink," a cutter, a filling machine, a capping machine, followed by a steam box for the preliminary cooking before sealing, two crimping machines[1] for fastening the caps to render the can air-tight, and the requisite steam autoclave capacity for the final cooking. Such an equipment gives a daily capacity of 900 cases of canned salmon, each case containing 4 dozen 1-pound cans, or 48 pounds of canned salmon. This estimate is based on a day of about 12 hours. During the canning season a "one-line" cannery, or one with a single unit, is expected to pack about 40,000 cases. The season's pack is determined by the skill of the management, the condition of the market, and the fortune of the fishermen.

LABOR.

As many of the salmon canneries of Alaska are situated in isolated and scarcely habitable places, laborers have to be imported. In southeastern Alaska the natives are employed to a large extent, as the men seem to prefer and to be more successful at fishing; they are not found engaged in the indoor occupations to the extent that might be expected. Women and children are employed in large numbers in the canneries, performing the light and easy tasks such as inspecting the cans for underweight, labeling, and packing, and, where the filling machine is not employed, filling the cans by hand. For this class of work the women receive 25 to 30 cents per hour and the children about half that sum. The industry of the Alaskan native is surprising to one who is accustomed to associate extreme indolence with the American aborigine. That no part of the canning industry is too complex for the skill of the Alaskan native is abundantly illustrated by the operation of the cannery at Metlakahtla, which is run on a cooperative basis. During the fishing season, entire villages may be deserted, and it is no uncommon sight to see entire families at work, the men at the fishing grounds and the women and children in the canneries.

This native labor is made use of so far as possible, but is entirely inadequate to meet the demands of the industry, therefore labor must be imported. The prevailing nationality thus imported probably is Chinese; there are also Filipinos, Mexicans, Japanese, and other races in smaller numbers. The laborers are hired in gangs, generally on a contract basis. The contractors most frequently are Chinese, and the contract binds the contractor to pack so many cases of salmon at a certain price. To a casual observer it appears that the industry has an abundance of laborers and that there are about two men

[1] The capping machine, the cooking box, and the two crimping machines constitute the solderless or "sanitary" canning apparatus proper.

for every position. This may be true or it may be only apparent, but after all it has but a slight bearing on the economy of the industry, as any superfluity in the number of laborers is paid for by the labor contractor and not by the packer.

Laborers are provided for but one shift per day; therefore the working day can not be considered to be of more than 12 hours. The cannery may operate for a longer period, as the various departments are not operated simultaneously. Thus the dressing gang invariably begins work before those attending to subsequent operations.

As the forces are organized with a view to the maximum daily pack of the cannery, there are usually more laborers than is actually necessary for the average daily pack. Furthermore there are many days preceding the rush of the season when there are no fish at all to pack. At this time there are many things to be done to get the cannery in readiness for the season's operations, conspicuous among which is the manufacture of the tin cans to hold the fish and the wooden cases to receive the packed cans. But on the whole it may be said that there are frequent periods when one part of the cannery force or another is idle.

The laborers are organized in the Pacific coast cities of the States and are taken to the canneries frequently in the ships of the operators. For those going to western Alaska it is practically impossible to obtain additions to their force during the operating season. Those operators situated in central and southeast Alaska are on or near steamship lines and can secure additions to their force on comparatively short notice. The former circumstance makes it necessary for the operators of the western Alaska district to "carry" their corps of employees from the time of their departure from the States to their return. This period includes the time consumed in the ocean voyage in a sailing vessel from the city of their departure to the scene of the summer's activity.

PRODUCTION OF CANNED SALMON.

The number of cases of canned salmon packed on the Pacific coast during the season of 1913 is shown, by grades, in Table III.[1]

[1] Pacific Fisherman, 12, No. 1 (Special), 36 (1914).

TABLE III.—*Pacific coast canned salmon pack for 1913.*

District.	Kings, springs, chinooks.			Reds, sockeyes, bluebacks.			Medium reds, cohoes, silversides.		
	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.
Alaska	32,840	....	1,327	1,917,961	17,628	28,790	73,218	721	3,438
Puget Sound	716	518	....	967,119	485,426	220,554	20,440	38,354	2,225
Columbia River	28,738	96,633	66,745	....	....	11,152	10,437	19,408	11,124
Sacramento River	....	950	....	....	....	....	....	....	....
Outside streams	4,827	6,957	4,172	13,458	5,778	3,381	24,011	12,893	13,942
Total American pack	67,121	105,058	72,244	2,898,538	508,832	263,877	128,106	71,376	30,729
British Columbia	34,282	1,579	5,188	290,063	270,368	411,747	52,937	7,946	8,939
Total pack of entire coast	101,403	106,637	77,432	3,188,601	779,200	675,624	181,043	79,322	39,668

District.	Pinks, humpbacks.			Chums.			Steelheads.			Total.
	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.	1-pound talls.	1-pound flats.	½-pound flats, 8 dozen.	Full cases.
Alaska	1,377,586	4,766	20,564	261,161	5,668	825	......	......	......	3,746,493
Puget Sound	761,776	17,167	12,943	54,100	2,125	......	......	......	......	2,583,463
Columbia River	......	......	......	13,181	......	122	1,137	3,785	4,017	266,479
Sacramento River	......	......	......	......	......	......	......	......	......	950
Outside streams	4,141	159	177	17,349	316	......	600	......	......	112,161
Total American pack	2,143,503	22,092	33,684	345,791	8,109	947	1,737	3,785	4,017	6,709,546
British Columbia	148,799	12,928	31,160	76,369	1,596	......	......	......	......	1,353,901
Total pack of entire coast	2,292,302	35,020	64,844	422,160	9,705	947	1,737	3,785	4,017	8,063,447

CENTERS OF THE INDUSTRY.

The salmon-packing industry of the United States is centered mainly in four localities: The Columbia River, Puget Sound, southeastern Alaska, and western Alaska or the Bristol Bay region. The industry along the Columbia River is distributed from The Dalles, Oreg., to the mouth of the river, though the greatest number of canneries is located near the mouth of the river, in the neighborhood of Astoria. On Puget Sound, the industry is centered around Bellingham, Anacortes, and Port Townsend; there is an additional number of canneries in the Grays Harbor vicinity, on the Straits of Fuca. In southeast Alaska the canneries are distributed over the large area of islands and fiords extending from the Icy Straits to Dixon Entrance. In western Alaska they are situated principally on Bristol Bay. The locations of the various canneries in Alaska are shown in figures 1 and 2.

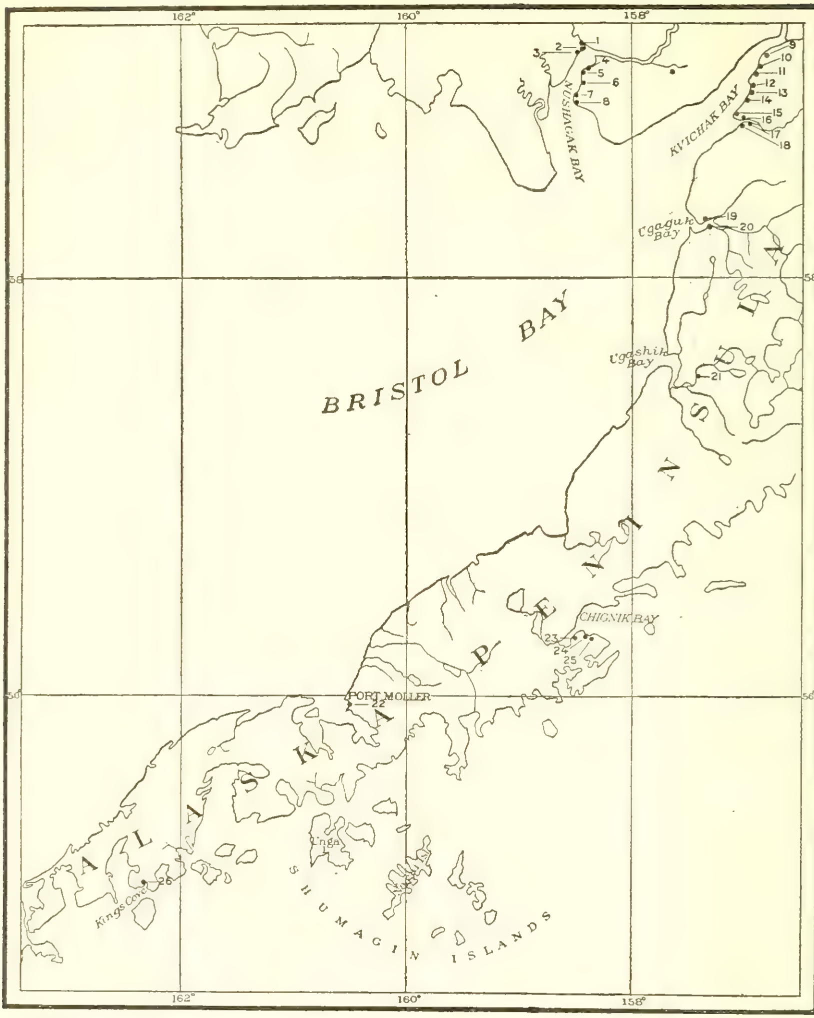


FIG. 1.—Sketch map showing location of the canneries on the peninsula of Alaska.

KEY TO LOCATION OF CANNERIES.

1. Alaska Salmon Co., Nushagak Bay (Wood River).
2. Alaska Portland Packers' Association, Nushagak Bay (Wood River).
3. Alaska Packers' Association, Nushagak Bay (Wood River).
4. Northwestern Fisheries Co., Nushagak Bay (Wood River).
5. Alaska Fishermen's Packing Co., Nushagak Bay (Wood River).
6. Columbia River Packers' Association, Nushagak Bay (Wood River).
7. Alaska Packers' Association, Nushagak Bay (Wood River).
8. North Alaska Salmon Co., Nushagak Bay (Wood River).
9, 10. North Alaska Salmon Co., Kvichak River.
11, 12. Alaska Packers' Association, Kvichak River.
13. Alaska Fishermen's Packing Co., Kvichak River.
14. Bristol Bay Packing Co., Kvichak River.
15. Naknek Packing Co., Naknek River.
16, 17, 18. Alaska Packers' Association, Naknek River.
19. North Alaska Salmon Co., Ugaguk River.
20. Alaska Packers' Association, Ugaguk River.
21. Red Salmon Canning Co., Ugashik River.
22. Pacific American Fisheries. Port Moller.
23. Northwestern Fisheries Co., Chignik.
24. Columbia River Packers' Association, Chignik.
25. Alaska Packers' Association, Chignik.
26. Pacific American Fisheries, King Cove.

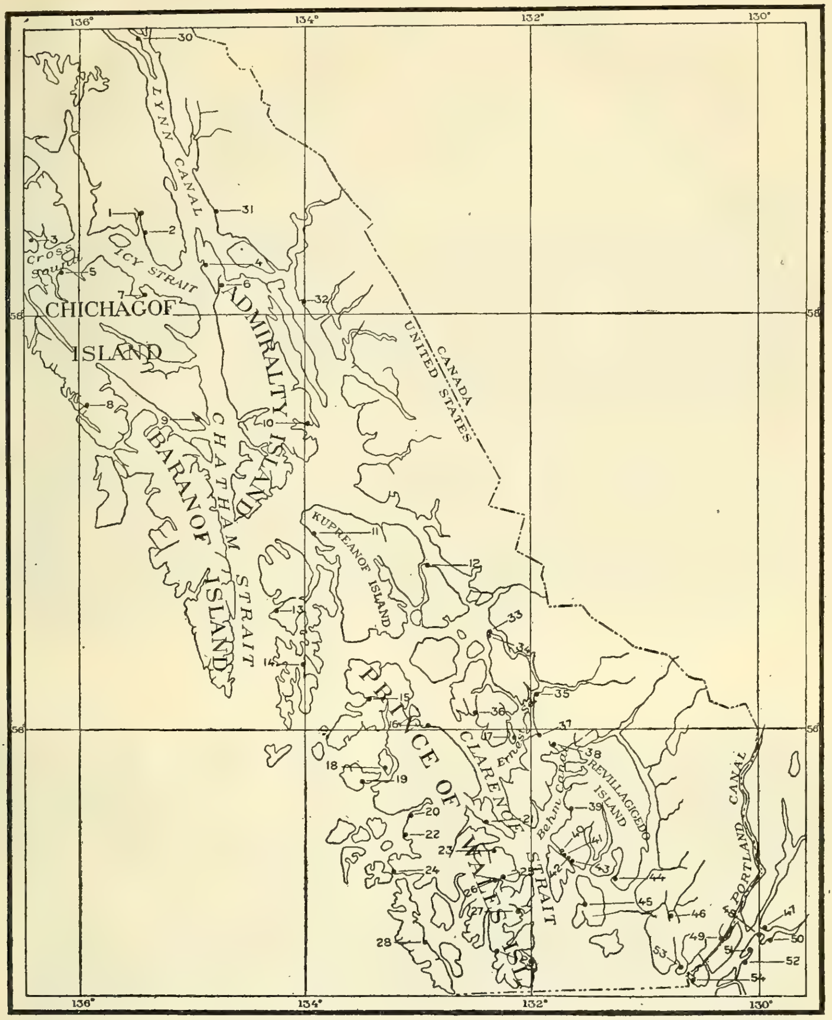


FIG. 2.—Sketch map showing location of the canneries in southeastern Alaska.

KEY TO LOCATION OF CANNERIES.

1. Pacific American Fisheries, Excursion Inlet.
2. Astoria & Puget Sound Packing Co., Excursion Inlet.
3. Northwestern Fisheries, Dundas.
4. Thlinket Packing Co., Hunter Bay.
5. J. B. Nelson (proposed).
6. Hawk Fish Co., Hawk Inlet.
7. Hoonah Packing Co., Hoonah.
8. Deep Sea Canning Co., Chicagof.
9. Geo. T. Meyers & Co., Chatham.
10. Admiralty Trading Co., Gambier Bay.
11. Kake Packing Co., Kake.
12. Pacific Coast & Norway Packing Co., Petersburg.
13. Pillar Bay Packing Co., Point Ellis.
14. Kuiu Island Packing Co., Port Beauclerc.
15. Shakan Salmon Co., Shakan.
16. F. C. Barnes & Co., Lake Bay.
17. Canoe Pass Packing Co., Canoe Pass.
18. Irving Packing Co., Karheen.
19. Swift, Arthur & Co., Heceta.
20. North Pacific Packing & Trading Co., Klawack.
21. Kasaan Salmon Co., Kasaan.
22. Lindenberger Packing Co., Fish Egg.
23. Scowl Arm Packing Co., Scowl Arm.
24. Oceanic Packing Co., Waterfall.
25. Sunny Point Packing Co., Sunny Point.
26. Alaska Pacific Fisheries, Chomley.
27. Starr, Collinson Co., Moira Sound.

KEY TO LOCATION OF CANNERIES—Continued.

28. Wiese Packing Co., Rose Inlet.
29. Northwestern Fisheries, Hunter Bay.
30. Alaska Pacific Fisheries, Chilkoot.
31. Tee Harbor Packing Co., Tee Harbor.
32. Taku Canning & Cold Storage Co., Taku.
33. Alaska Packers' Association, Wrangell.
34. Alaska Sanitary Packing Co., Wrangell.
35. Point Warde Packing Co., Point Warde.
36. Sanborn, Cram Co., Burnett Inlet.
37. Northwestern Fisheries, Santa Anna.
38. Alaska Pacific Fisheries, Yes Bay.
39. Alaska Packers' Association, Loring.
40. Walsh, Moore Co., Ward Cove.
41. Revilla Fish Products Co., Ketchikan.
42. Pure Food Fish Co., Ketchikan.
43. Fidalgo Island Packing Co., Ketchikan.
44. Lindenberger Packing Co., Roe Point.
45. Metlakahtla Industrial Co., Metlakahtla.
46. Northwestern Fisheries Co., Quadra.
47. Kincolith Packing Co., Mill Bay, British Columbia.
48. British Columbia Packing Association No. 2, Nass Bay.
49. Hidden Inlet Packing Co., Hidden Inlet.
50. British Columbia Packers' Association, Nass Harbor, British Columbia.
51. Anglo-British Columbia Packing Co., Port Nelson, British Columbia.
52. Anglo-British Columbia Packing Co., Arrandale, British Columbia.
53. Herbert Hume, Nakat Inlet.
54. M. Des Brissay & Co., Wales Island, British Columbia.

In the following table is given the production of the various centers during the packing seasons 1909–1913, inclusive.[1]

TABLE IV.—*Production of canned salmon in the United States and Alaska, by districts, during the years 1909–1913, inclusive.*

District.	Number of cases packed.				
	1909	1910	1911	1912	1913
Puget Sound	1,632,949	567,883	1,557,029	416,125	2,583,463
Grays Harbor	19,787	51,130	61,671	54,507	54,922
Willapa Harbor	12,024	14,508	25,850	24,887	8,422
Columbia River	274,087	391,415	543,331	285,666	266,479
Oregon coastal streams	58,169	103,617	153,828	77,765	42,441
Klamath River, Cal	5,633	8,016	7,604	20,000	6,376
Southeastern Alaska	852,870	1,066,399	1,580,868	2,033,648	1,793,851
Central Alaska	391,054	432,517	499,743	625,062	477,267
Western Alaska	1,151,553	914,138	743,206	1,395,931	1,505,375

THE WASTE PRODUCED IN THE CANNING OF SALMON.

AMOUNTS.

The waste produced in the process of canning salmon is variously estimated to be from 25 to 50 per cent of the original or "round" weight of the fish. The percentage of waste varies with the kinds of salmon, being greater with small than with large fish. It probably is true also that in canning the more expensive grades, which also are the larger fish, greater precautions are taken to reduce the waste than with the cheaper grades. In the case of the larger fish—the "reds"—perhaps the portion thrown away is more nearly 25 per cent than 50 per cent. Therefore, in considering the problem of preparing the waste for use as fertilizer and in estimating the quantities of material available it must be specified what grades of fish are being dealt with.

[1] From statistics published by the Pacific Fisherman, January, 1914.

FIG. 1.—GENERAL VIEW OF AN ALASKAN CANNERY.

FIG. 2.—GENERAL VIEW OF AN ALASKAN CANNERY.

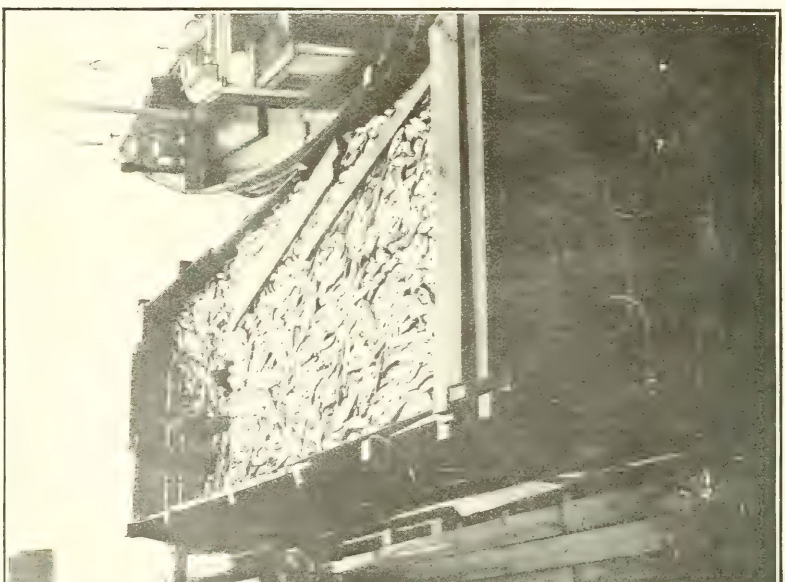


FIG. 1.—UNLOADING SALMON AT AN ALASKAN CANNERY.

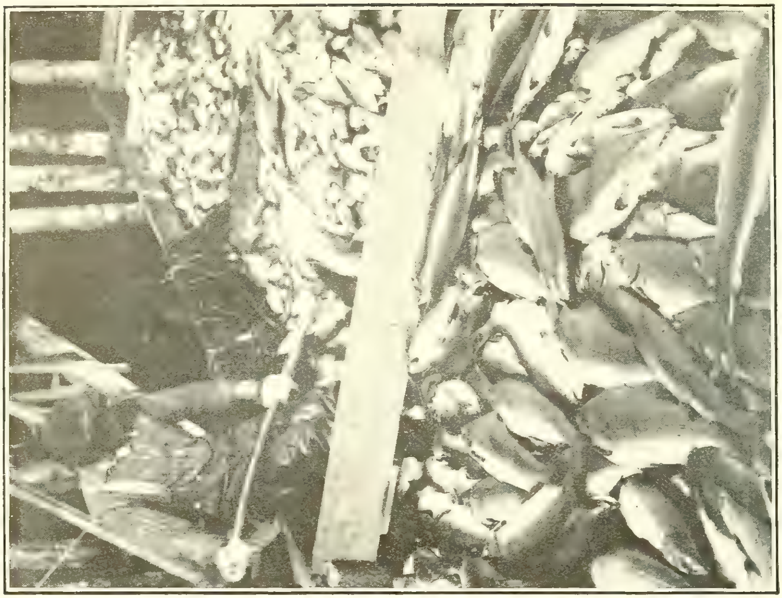


FIG. 2.—UNLOADING "HUMP-BACK" SALMON AT AN ALASKAN CANNERY.

FIG. 1.—INTERIOR OF FISH-CANNING ROOM OF AN ALASKAN CANNERY, SHOWING TWO "IRON-CHINKS" IN POSITION.

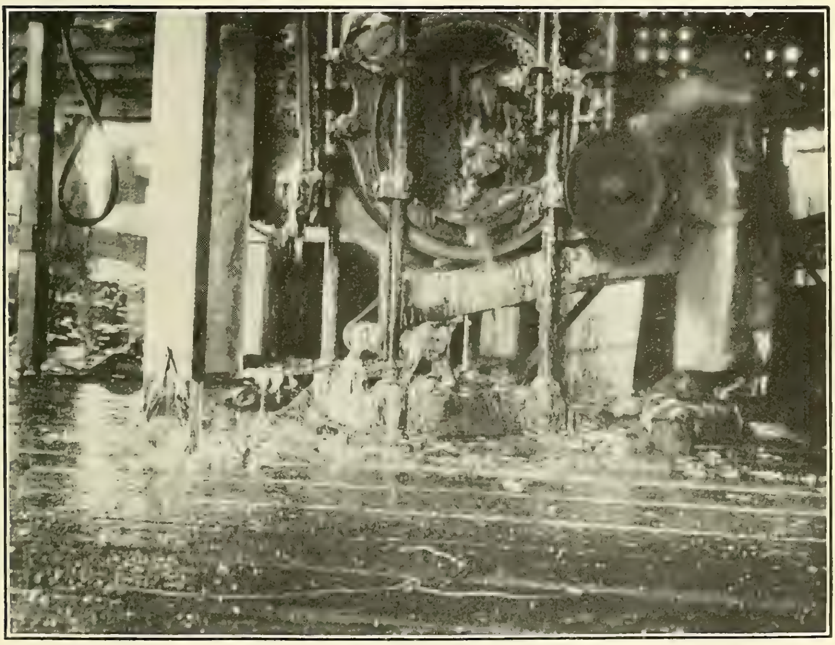
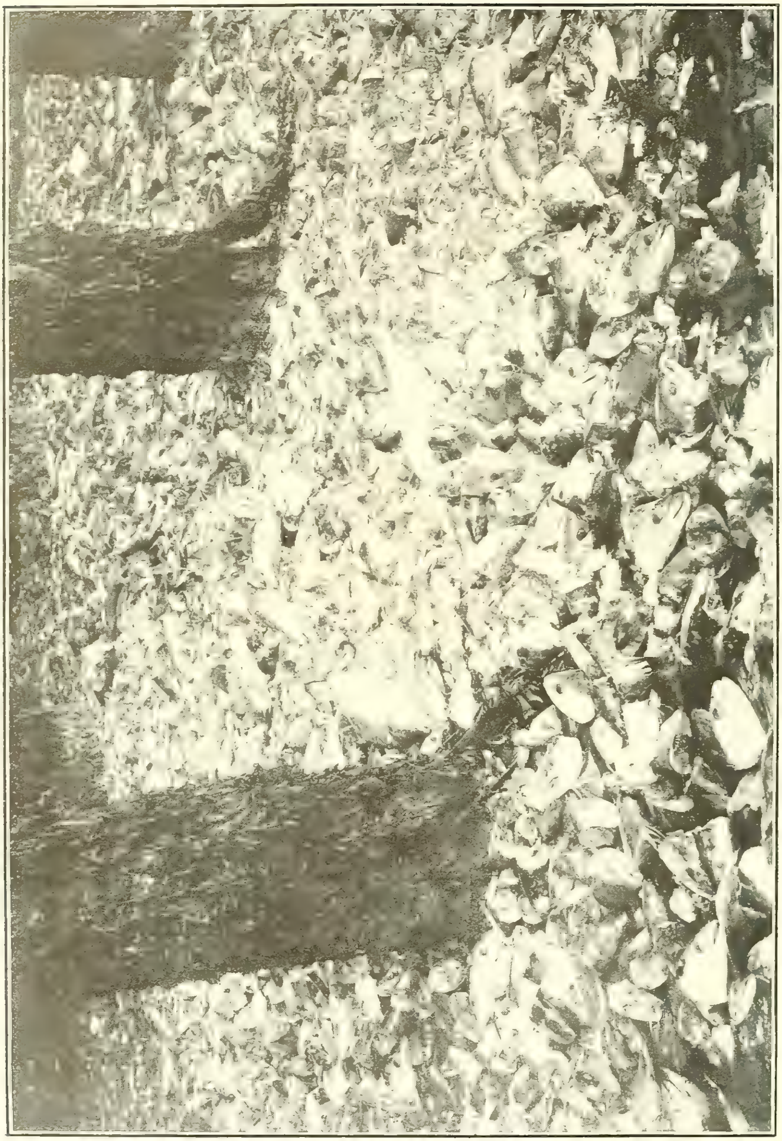


FIG. 2.—THE "IRON-CHINK" IN USE.



CANNERY WASTE EXPOSED AT LOW TIDE ON THE BEACH BENEATH AN ALASKAN CANNERY.

In general, it is sufficient to designate the region under consideration, as the various centers of the industry are characterized by certain grades. Thus, in the Bristol Bay region of Alaska the pack consists of 94 per cent red fish, or sockeyes. In southeastern Alaska, between Icy Straits and Dixon Entrance, the total pack contains about 1 per cent of "reds." In many canneries the proportion of red fish put up is negligible. In the Puget Sound region the composition of the pack varies with the year. In years of a large run of sockeyes, as in 1913, the pack may contain as much as 65 per cent of the red salmon. In other years, as in 1912, it may comprise only 45 per cent of sockeyes. In the three seasons preceding the last, 1910, 1911, and 1912, the average composition of the packs on Puget Sound was 22 per cent "reds." On the Columbia River the pack is composed almost entirely of red fish. While the figure which represents the exact proportions of waste from the red fish is not known, it can be said with a fair degree of accuracy that the waste from humpbacks is from 40 per cent to 50 per cent of the round weight. Thus, to fill a case of 48 1-pound cans, from 17 to 19 5-pound salmon are required. On this basis, a round weight of from 85 to 95 pounds is reduced to 48 pounds, representing a waste of from 37 to 47 pounds per case. For the sake of conservativeness in this discussion, 40 pounds per case has been taken to represent the waste from humpbacks and 30 pounds per case that from the "reds." On the basis of the foregoing figures representing the total pack of salmon, taking 30 pounds per case as representing the loss from red salmon and 40 pounds per case from the others, the amount of cannery waste produced by centers may be estimated. Likewise the value has been computed on the basis of $15 per ton, the value fixed by present commercial operations. The following table gives the amount of cannery waste and its value:

TABLE V.—*Amount of cannery waste produced and its value.*

Region.	Cases packed.		Waste.			Value.
	"Reds."	Others.	"Reds."	Others.	Total.	
			Tons.	*Tons.*	*Tons.*	
Columbia River	266,479		4,000		4,000	$60,000
Puget Sound	1,673,099	910,634	25,100	19,700	44,800	672,000
Southeastern Alaska	180,685	1,613,150	2,700	32,260	34,960	524,400
Western Alaska	1,419,441	85,934	21,290	1,700	22,990	344,850
Central Alaska	364,253	83,014	9,960	1,660	11,620	174,300
Grays Harbor, Willapa Harbor, and Oregon coastal streams	[1] 105,785		1,540		1,540	23,100
United States					119,910	1,798,650
British Columbia	[1] 1,353,900		20,300		20,300	304,500
Pacific coast					140,210	2,103,150

[1] Computed as "reds."

CHARACTER OF WASTE.

The first waste involved in the canning of salmon to be considered in this discussion is the waste of fish other than salmon taken with them in seines and traps. This varies widely from day to day and with the place and method of fishing. At best it is a matter of great uncertainty. Thus, in a scow load of 30,000 salmon taken from a trap under the observation of the writer, there was an entirely negligible number of fish other than salmon, while from another trap it was recorded that the catch was made up of approximately 50 per cent of salmon and 50 per cent of other fish. Of the salmon about 1 per cent was dog salmon, a slightly larger proportion was humpbacks, 10 per cent was cohoes, and the balance, about 88 per cent, was sockeyes. Among the other fish taken, a number equal to that of the salmon, were trout, tomcod, flounders, and dog fish. Where the proportion of fish other than salmon taken in traps is so great, they are thrown from the scow as fast as brailed into it; while if the proportion be small, they are permitted to remain. When the fish are unloaded at the cannery these are thrown overboard by the unloaders as encountered, or, frequently, the edible fish are picked out by children or adults from among the laborers around the cannery and are used for food. Aside from the fish so consumed, there is a considerable number of food fish for which there is no demand, as well as nonedible fish, such as dogfish, which easily could be made available as a supplementary source of material from which to prepare fertilizer and oil. However, from the casual observations of a summer spent in and around the salmon canneries and from the answers to casual inquiries regarding the matter, it must be said that as a source of such material the fish other than salmon, taken incidentally in the salmon fisheries, are too uncertain and too variable in amount to be given very serious consideration. Undoubtedly, in the aggregate they form a considerable supply, and a large part of it could be made available for fertilizer manufacture. But in view of the many elements of uncertainty involved, it perhaps is unnecessary to speculate further upon the bearing of this supply on the problem under discussion.

In the neighborhood of some of the canneries to-day, where the waste from the dressed salmon is thrown into the water, there are seemingly hordes of dogfish. These could be taken with the utmost ease and would make an abundant source of material on which to operate a fertilizer plant. It must be borne in mind, however, that when the food supply which now attracts them to the canneries is cut off, as it would be if a by-products plant were instituted in connection with the cannery, they would cease to congregate there in such numbers. Also, if attacked by any of the present methods of fishing with hook and line or seines, it is possible that they would desert the waters where so attacked.

In past years it has been true that in the height of the fishing season, when the salmon were most abundant, large numbers were thrown away. The reasons for this lay in the fact that more salmon were caught and delivered at the canneries than could be preserved. With the fish delivered, it remained only to do what the circumstances showed was the logical thing—to discard the less valuable part of the excess delivery and preserve the more valuable. The error, of course, lay in permitting the delivery of such large quantities of fish. Once this error was committed the resulting waste was unavoidable. Even to-day, with the increased demand for fish and greater facilities for communication, there occasionally occurs a similar waste. During the summer of 1913 the civic authorities of Anacortes, Wash., were called upon to take action to protect the city from the nuisance resulting from the dumping of "many thousand" of salmon into the harbor.[1]

Such an oversupply of fish at a cannery is liable to occur at any time during the period of greatest abundance of fish as long as the present methods of securing the fish are employed. In localities where there are several canneries in operation it is frequently possible to sell the surplus taken by one cannery to supply the needs of another. But where all the canneries are pursuing the fish with equal success, it is evident that a superfluity for which there is no demand is likely to occur.

It is most desirable that these fish be allowed to remain at liberty and to continue on their way to the spawning grounds. But once taken and allowed to die, any use whatever is preferable to throwing them back into the water to cause pollution and create a nuisance. In case of a by-products plant being in operation as an adjunct to or in the neighborhood of a cannery, the logical thing would be to render for fertilizer and oil the oversupply of salmon. A law which would permit the capture by the packers of more fish than could be used for food, if at all reasonable, would permit their use in this manner.

A circumstance which would militate against this incidental supply of raw material being of probable value to a by-products plant is the fact that it would be available only while the cannery is being operated at maximum capacity and, on rare occasions, when, through some mishap, the operation of the cannery temporarily is suspended. The capacity of a by-products plant quite possibly would be such as to enable it to treat only the maximum output in waste of the cannery or canneries, and in that case it would not be able readily to

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[1] The American-Reveille, Bellingham, Wash., Sept. 2, 1913.

adapt itself to such a sudden increment in the amount of material to be handled.

A practice formerly much in vogue and still used to a small extent is that of curing what is known as "salmon bellies." The thin ventral walls of the fish are cut out, with a single stroke of a knife, and are packed in salt. They are considered a great delicacy. The remainder of the salmon, consisting of the greater part of the muscular portion, is thrown away. To what extent this practice prevails it is impossible to say, as the "salmon bellies" at times are prepared by members of the fishing gangs, ostensibly for their own use, while on the way from the fishing grounds to the canneries, the refuse being thrown overboard. In case of the institution of by-product plants in connection with canneries, the waste produced from this source should be investigated with a view to its utilization. Only when some use is made of the discarded greater portion of the fish can this extremely wasteful practice be justified.

In addition to the "salmon bellies" prepared by those associated with the fishing industries for their own consumption, 1,118 barrels are reported as prepared for the market—468 barrels in Alaska and 650 in the State of Washington. In some cases the residual salmon is salted also; to what extent can not be determined from the statistics available. It is probable that the portion preserved as the "belly" is about 10 per cent of the whole salmon. The residue from the preparation of 1,118 barrels of 200 pounds each would amount to about 1,000 tons.

In the dressing or "butchering" of the fish the first operation is the severing of the head. This is true whether the dressing is done by hand or by machine. If by hand the head is severed by the first of two "butchers" working together, the second of whom opens the fish and removes the viscera. If by machine, as has been described, as the fish enters the machine it is lifted against a knife which severs the head. In either case the head is cut off as a separate operation. This circumstance makes it a simple matter to collect the heads separately from the other waste.

The balance of the waste is produced together, whether coming from the knives of the human operator or the machine. It consists of the roe, the entrails and other viscera, and the fins and tails. With the fins are cut off portions of the flesh, and with the tail at least 2 inches of the fleshy portion of the fish is severed. The stomach and entrails make up only a small portion of this material. Certain species of the salmon after they start on their course toward the spawning grounds, or certainly after they reach fresh or brackish water, it is said, take no food whatever. The alimentary tract of the fish caught near the shore is small and shriveled and quite empty. The energies required by the subsequent activities of the fish and the elements necessary for the further development and ripening of the roe are supplied through the metamorphosis of the materials already stored up within the body of the fish. The weight of the roe probably about equals that of the other waste produced with it; and that of the roe, fins, and tail, combined, probably equals that of the head. The roe, then, according to this estimate, makes up about 25 per cent of the weight of the waste produced in the cannery; and the head, according to the same estimate, about 50 per cent. Therefore about one-half of the materials designed for hypothetical rendering plants would be in the form of compact lumps, rather clean in nature, and easily handled (the heads). In this connection it may be said that during seasons of abundant materials some of the rendering plants now in operation make a practice, so far as possible without complicating the methods, of collecting only the heads. As the material is being loaded upon the scow for transportation to the rendering plant, streams of water are allowed to play over it until most of the finer matter is washed out and practically only the heads remain. This practice is followed because of the greater facility with which the heads can be rendered. The roe contains more gelatinous material, which adds to the difficulties of pressing.

An additional though small amount of waste is found in the water from the "slimers'" tables. This consists of the small strings of the viscera and of pieces of fins still adhering to the fish after having passed through the mechanical cleaner, and of the clots of blood which lie along the dorsal portion of the body cavity.

The entire mass of waste, with the exception of the heads, is moved by streams of water. Any system of collecting it entirely must depend on handling—to begin with, at least—the entire volume of water. It is a happy circumstance that all of this material has a higher specific gravity than has water, so that a complete separation of it from the water is possible simply through settling. This applies to every part of the waste, except, of course, the dissolved blood. The dilution of this solution makes its treatment for the recovery of the blood of doubtful economy. Since the final elimination of this large volume of water is so easy, no particular advantage is to be gained from the reduction of its volume so long as that reduction involves the loss of valuable solids. For that reason it probably would prove most advantageous to include the entire volume of water used in the various cleaning operations in any process for the collection of the by-products. In other words, since the separation of the solids from the liquids is so easily accomplished by simply permitting the former to settle out, but very little more expense would be involved in using a large than a small volume.

The physical composition of the waste produced in the cleaning house, then, is the heads, forming large lumps, the tails in smaller lumps, together with a more or less finely divided and slimy mass of roe, pieces of flesh, and viscera. In rendering, the fleshy and bony portions withstand cooking with less tendency to disintegrate, as they are composed largely of muscular tissue on a framework of bone and cartilage. The roe, the milt, and the viscera are of much softer structure and are readily disintegrated. If the roe has reached that stage of development where the individual eggs have attained the size of peas, each has an envelope which is hardened and toughened by cooking or drying, and the albumen constituting the major portion of the egg is readily coagulated by heat. Materials which retain their structures under the cooking action of steam are rendered easily, while those which, on the contrary, disintegrate into an amorphous mass present serious difficulties. The preponderance of heads and fleshy pieces in the waste from the salmon canneries is a very favorable circumstance.

The waste as it is removed from the cannery floor is fresh, with but slight odor, and is practically entirely free from foreign substances. As most of the canneries are located in regions of comparatively cool climate, there is not a very strong tendency for the waste to spoil. This is particularly true of Alaska. On Puget Sound periods of warm weather of sufficient duration and severity to induce rather rapid decomposition in the waste may be expected. Altogether, the material is remarkably clean and inoffensive. And in a by-products plant in which the waste is rendered as fast as produced, the odors arising therefrom should be no more undesirable than those already liberated from the salmon cooking in the cannery proper. This odor, the odor of steamed salmon, can not be considered objectionable from a sanitary point of view.

OTHER SALMON-PRESERVING INDUSTRIES.

The preservation of salmon in salt constitutes an industry of considerable extent, though it scarcely compares with the canning industry in importance. It results in the production of large amounts of waste, and deserves attention as a possible auxiliary source of raw materials, under favorable conditions, for a possible adjacent rendering plant. The extent to which this method of preserving is carried on at any one station is scarcely great enough to warrant the installation there of a by-products plant to render the waste.

In Alaska, during the past season, "mild-curing" (the preservation by the aid of a small amount of salt combined with cold storage) was prosecuted to the extent that 7,443 tierces, of 800 pounds each, were prepared.[1] The greater proportion of this was packed in southeast Alaska. In the States, 3,621 tierces were packed on Puget

[1] Bower and Fassett, Pacific Fisherman, 12, No. 1 (Special), 58 (1914).

Sound, 300 on the Washington coast other than Puget Sound, 5,746 on the Columbia River, 2,381 on the Oregon coast, 4,789 on the Sacramento River, and 550 on Monterey Bay.[1] The waste in "mild-curing" amounts to about 25 per cent, or 250 pounds per tierce. The total waste in the industry, then, is about 3,100 tons.

Of pickled or salted salmon, 37,841 barrels of 200 pounds each were prepared in Alaska. Most of this was packed in western Alaska. In the State of Washington an additional number of 4,610 barrels were packed. The waste from this branch of the salmon-packing industry, on the basis of 25 per cent, or 75 pounds per barrel, amounts to 1,587 tons.

CHEMICAL COMPOSITION OF THE RAW CANNERY WASTE.

Analyses of samples of the waste from humpback salmon were made by J. R. Lindemuth, of the Bureau of Soils. The material from which the samples were taken was collected from the floor of a cannery in Alaska; after the addition of formaldehyde, it was sealed in tin for shipment. While its preservation was not perfect, the changes which took place within it during transshipment are not considered great enough to have altered materially its ultimate chemical composition or to have lessened the value of the subsequent analysis. From this material three samples were prepared, one of heads, one of fins and tails in equal proportions, and one of roe and milt in equivalent proportions.

Moisture was determined by evaporating to dryness a definite weight in a steam bath at a temperature of 100° C. Nitrogen, oil, and phosphoric acid were determined in the dry samples by the usual methods of analysis. In the last column of the tables are given the figures representing the content in oil, in gallons per raw ton, of the different samples. This figure is arrived at by calculating to gallons from the percentage composition of the dry sample of each, the value 0.925 being taken to represent the specific gravity of the oil.

TABLE VI.—*Analyses of samples of the raw material produced as waste in the mechanical dressing of "humpback" salmon.*

[Material taken from the floor of the cannery of the Pure Food Fish Co., Ketchikan, Alaska, July, 1913.]

Character of sample.	Moisture.	Nitrogen.	Phosphoric acid.	Bone phosphate $Ca_3(PO_4)_2$	Oil.	Oil per ton.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Gallons.*
Roe and milt (50 per cent each)	68.7	3.68	1.08	2.35	3.18	8.24
Heads	63.2	2.65	1.54	3.36	13.70	35.51
Fins and tails	63.26	3.11	2.20	4.80	11.16	28.94
Average	64.6	3.02	1.59	3.46	10.43	27.05

[1] Salt Fish Statistics, ibid., 85 (1914).

TABLE VII.—*The results reported in Table VI, recalculated to the water-free basis.*

Character of sample.	Nitrogen.	Phosphoric acid.	Bone phosphate $Ca_3(PO_4)_2$	Oil.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Roe and milt	11.76	3.44	7.50	10.16
Heads	7.20	4.18	9.13	37.22
Fins and tails	8.46	5.98	13.06	30.37
Average	8.65	4.44	9.70	28.74

The value representing the average composition of cannery waste is arrived at by adding the figures for the percentage composition of the heads, taken twice, and of the roe and the fins and tails. The values for the heads are multiplied by two, because, as it will be remembered, the heads are estimated to make up 50 per cent of the waste; while the roe and the fins, with the tails, are estimated to constitute 25 per cent each.

From this table it appears that the heads are richer in oil than the other parts of the waste. This is to be expected, and agrees with the facts as established practically in the rendering plants operating on this material. The nitrogen content of the heads is correspondingly low. As it is the oil which constitutes the greatest value among the substances recovered, this fact makes the heads the most valuable part. The high nitrogen content of the roe is to be expected, as it is made up to such a large extent of albuminous compounds. Its low content in oil likewise conforms to one's preconceived ideas.

On the basis of the analysis reported in Table VI, the value of the raw cannery waste may be computed.

The percentage of nitrogen, 3.02, is equivalent to 3.67 per cent ammonia, NH_3. This, in the retail market, may be expected to bring $3.20 per unit (a unit being 1 per cent); bone phosphates is valued at 10 cents per unit; and oil at 30 cents per gallon. Then:

3.67 per cent NH_3, at $3.20 per unit	$11.74
3.46 per cent bone phosphate, at 10 cents per unit	0.34
27.05 gallons oil, at 30 cents per gallon	8.12
Total value per raw ton	20.20

By present methods the manufacturers of fertilizer and oil from this material expect to recover about $15 in values. Present methods, then, can be considered as only 75 per cent efficient. In further substantiation of this conclusion are the results published by Thomas.[1]

[1] A. M. Thomas, Waste in Salmon Canning Industry. Pacific Fisherman, 12, No. 2, 26 (1914).

The averages of all experiments show the following facts: Each ton of salmon offal treated produced 800 pounds of mixed oil and fertilizer. Of this amount 200 pounds was salmon oil and 600 pounds oil-free fertilizer. The average analysis of the fertilizer thus produced was—ammonia, 14.3 per cent; bone phosphate, 13 per cent.

Estimating the 200 pounds of oil as being 25 gallons, at a price of 32 cents, which seems a fair average, we have, then, for each ton of offal treated an oil value of $8, and, estimating the value of a unit of ammonia at $3.20 and bone phosphate at 10 cents per unit, we have a fertilizer value at—14.3 per cent ammonia, at $3.20, $45.76; 13 per cent bone phosphate, at 10 cents, $1.30; or a total value of $47.06 per ton.

Then, at 600 pounds of fertilizer of this quality to the short ton of offal treated, we have $47.06×0.3=$14.12, the fertilizer value of 1 ton of offal, which gives a total available value of 1 ton of offal as—fertilizer, $14.12; oil, $8; total value, $22.12.

METHODS OF DISPOSAL OF WASTE.

It already has been stated that the first waste incident to the salmon-canning industry consists of throwing overboard the fish unfit for food and food fish for which there is no demand taken incidentally with the salmon. It has also been pointed out that the second waste, considered in the order of the manipulation of the fish prior to canning, consists in the occasional discarding of scowloads of salmon for which there is no demand.

In the succeeding operation of dressing the fish the head is severed first. If severed mechanically it falls directly into a chute leading beneath the cannery floor; if by hand, it, together with the viscera, is washed into a chute by water flowing through a trough at the back of the "butchers'" table. Where the dressing is mechanical, the severing of the head and the removal of the viscera are performed as separate operations by the same machine. The head falls into a chute which directs it beneath the cannery floor. The viscera fall through an opening in the floor situated directly beneath the machine. As there is considerable spattering, the floor around the machine is liberally covered with the waste. After a consignment of fish has been cleaned, or at the end of the day's work, the material on the floor is washed into the opening beneath the machine, or through the cracks, purposely large, in the floor. That produced by the operations of the "slimers" likewise is conducted beneath the cannery floor. From this point, all of the waste, whatever its source, is treated together or similarly.

In southeastern Alaska the common practice is to permit all the waste to fall into the water beneath the cannery. As it is heavier than water it sinks to the bottom. In certain instances it is exposed at low tide (see Pl. V), though generally the water is of sufficient depth to cover it. In certain localities it is devoured by dogfish as fast as produced, while at other canneries a few miles distant these scavengers are strangely missing. In some cases the tidal currents carry the waste away, while in others, again, it accumulates on the bottom throughout the season. In such instances fermentation takes place slowly, with the production of obnoxious gases, which may be liberated slowly or may be held within the mass and released in large volumes and with considerable force. In a few instances in Alaska the waste enters chutes beneath the cannery floor, which conduct it to deep water at a distance from the cannery.

This practice has very serious objections. Practically always the waters around the canneries become fouled through the putrefaction of this waste in the water. Even though it may fall upon the bottom beneath the low-water mark, putrefaction within it will cause it to rise to the surface and some of it will find its way to the beach beneath and close to the cannery buildings. The amount may be small, but it will be sufficiently great to taint the air with its odor and convey the impression of an insanitary cannery. The pollution of the waters of the neighborhood likewise most probably results in those waters being deserted by fish which do not feed upon the putrefying refuse. This has been pretty thoroughly established in other regions in the case of certain food fishes. It is safe to assume that other fish possess some of the same fastidiousness. This may appear to be a matter of slight moment; but there are those who believe, and whose belief seems entirely justified by the known facts, that the disappearance of the salmon from certain waters of the East where they once swarmed in great numbers has been caused by the pollution of those waters. To be sure, this is a belief and not a demonstrated fact, but to disregard it and the warning which it gives is to run a risk that the fishing industry can ill afford to take. Likewise, where the cannery is located close to a town the nuisance created by the polluted waters results in a feeling of antagonism on the part of the residents of such a settlement. To retain the sympathy of the residents of a neighborhood in which an industry is located is being recognized as a matter of importance. There is in Alaska already a lack of sympathy with the packers on the part of the residents, who show an inclination to regard them as being indifferent to the well-being of Alaska and Alaskans. It is even claimed that this feeling has found expression in recent legislative enactments.

In certain parts of the Bristol Bay region the lack of deep water near the cannery makes it necessary to carry the cannery waste away from the vicinity of the cannery. This is done by loading the waste upon scows and towing them out to deep water for emptying. The same practice is resorted to in certain regions on Puget Sound, where the nearness of towns makes the pollution of the waters of the harbor in this manner prohibitive. This method of disposal involves serious expense both in the construction and maintenance of scows and special loading devices and in the actual expense of towage, in addition to which is the inconvenience of applying the cannery tugs to such work during the height of the fishing season.

AMOUNT OF WASTE UTILIZED IN THE VARIOUS CENTERS.

COLUMBIA RIVER.

Of the 4,000 tons of cannery waste produced in the canneries of the Columbia River in 1913, only 800 tons were utilized for the manufacture of fertilizer and oil, leaving a balance of 3,200 tons which was thrown away. This amount was rendered in one fertilizer and oil plant situated near Astoria, Oreg. The raw materials for this plant were secured exclusively from the canneries of Astoria, a maximum haul of 7 miles. Its output in finished products during the season of 1913 was about 80 tons of dry fish scrap and 20,000 gallons of oil.

PUGET SOUND.

During the season of 1913 approximately 15,500 tons of raw cannery waste were treated in the fish-rendering plants of Puget Sound, with the production of 1,550 tons of dry scrap and 273,000 gallons of oil.[1] Four plants were in regular operation, one being situated at Seattle, two at Anacortes, and one on Lummi Island, opposite Bellingham. A fifth plant, of large capacity, situated on Eliza Island, near Bellingham, was undergoing its initial trial during the summer, but marketed no output. Of these plants, the four situated near the Bellingham-Anacortes center of the canning industry naturally obtained the bulk of their raw materials from the canneries of the immediate neighborhood.

ALASKA.

At present there is but one rendering plant operating on salmon waste in the entire territory. This is strictly a by-products plant as an adjunct to a cannery, and is designed for a capacity limited to the maximum output in waste of the cannery of which it forms a part. The equipment was installed just prior to the fishing season of 1913. Preliminary runs showed that the capacity of the drier was insufficient to dry the output of the digesters or to permit the plant to run at an economical rate. For that reason it was not operated throughout the season. It was operated long enough, however, to show that the process employed yielded a good quality of oil and dry scrap of entirely satisfactory composition and appearance.[2]

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[1] Pacific Fisherman, 12, No. 1 (Special), 1914.

[2] The analysis of this product is reported in Table VIII, on p. 33.

FISH SCRAP FROM SALMON WASTE.

From preceding paragraphs it is to be seen that during the last year a total of 1,630 tons of dried fish scrap and 286,000 gallons of oil were manufactured from the waste from salmon canneries on the Pacific coast of the United States. The amount of these products represents the output of five plants.

The methods employed in at least four of the five plants in all essentials are similar. The differences between them are chiefly in mechanical features and in the arrangement of the machinery within the plants. The same process is used in all of them. This consists in cooking the waste by steam, either in closed retorts under pressure or in open retorts, in pressing the cooked fish in one type of press to remove the water and oil, and drying the scrap. In the following paragraphs the methods in vogue in these rendering stations are described in some detail.

COLLECTING.

The waste is carried from the cannery to the rendering plant on scows. In cases where the floor of the cannery is high enough above the surface of the water the refuse from the various "butchering" operations can be run through chutes into the scows by gravity. There are instances, however, where this is not possible at high water, and it has been found necessary to install conveyors for loading the scows. These are arranged beneath the cannery floor. The material is delivered to them at the bottom of hopper-shaped receptacles which receive the waste from the cannery floor. Where the top of the scow at high tide is above the level of the cannery floor, two conveyors working together at an angle to each other are utilized, one bringing the material horizontally to the edge of the dock to which the scow is made fast and the other lifting it over the side of the scow. The conveyors may be operated by a small gasoline engine or by the same motive power that operates the mechanical cleaner or the cutter.

UNLOADING.

The charged scow is towed to the dock of the rendering plant, where it is unloaded mechanically. An adjustable bucket conveyor, of the wheat-elevator type, is rigged in such a manner that its free end can be thrust into the mass of material constituting the load of the scow. The load is thus lifted and deposited directly, or by means of an auxiliary conveyor, into storage bins. From these it is drawn off as desired into cooking vats. What is regarded as the best practice consists in raising the waste directly to bins situated over the cooking vats, which in turn are placed over the presses, so that only one lifting is necessary, and the material thereafter may pursue its course through the factory by gravity.

COOKING.

The upright, cylindrical retort is in general use. It is provided with openings in top and bottom for charging and discharging, respectively. If the fish is to be cooked under pressure the opening in the top is generally smaller than otherwise, so that it more readily may be closed and rendered tight enough to retain the steam at the pressure at which it is admitted to the retort.

The manner in which the steam is admitted and the length of time during which the charge in the retort is subjected to the cooking action of the steam vary from plant to plant. In certain instances the steam is injected at the bottom and allowed to permeate the mass of waste undergoing cooking. When it appears at and issues freely from the top the charge is deemed sufficiently cooked. In other cases the cooking is continued for 12 hours under a pressure of 20 pounds of steam. As each operator regards his methods as the best, it may be said that all of the methods give equal satisfaction.

After cooking, the charge may be allowed to stand to settle, or it may be drawn off at once into the presses. If the former procedure is observed, much of the oil released in the cooking rises to the surface and is drawn off in any suitable manner. In any case the charge is admitted to the presses hot. As a result of the cooking the material may be thoroughly disintegrated to form a thin soup, or it may be broken up into coarse particles. The only essential seems to be the disintegration of the heads.

What is considered a good practice is to run the charge as soon as sufficiently cooked from the retorts into a storage vat or "slush box." This is provided with steam coils so that the material may be kept hot. From this vat the cooked fish is admitted to the presses. This system admits of greater elasticity, making the rate of cooking independent of that of pressing.

PRESSING.

Presses of the hydraulic or the "knuckle" type are in general use. Owing to the fine state of subdivision of the material to be filtered, the part of the press functioning as a filter must have very fine apertures in order that the separation between liquids and solids may be effected. The readiness with which such fine material closes the apertures of a filter and retards separation necessitates a very large filtering surface for a comparatively small amount of material. These conditions are fulfilled in the salmon-waste filter presses by the use of a heavy and compactly woven sort of burlap bagging ("hop cloth"), in which only small portions of the waste are put to be pressed.

The charge for the presses is made up in the following manner: A framework of 1-inch strips of wood inclosing a square of about 3 or 4 feet is placed on a truck and over it is thrown a square of the burlap. This makes a shallow receptacle, which is filled to the depth, perhaps, of about 3 inches with the material to be pressed. Then the loose edges of the burlap are folded over on top of the material so that it is entirely covered. On top of this is placed a square, of about the same dimensions, of wooden slats, held together by a suitable framework. On the slats is placed a second frame and a second square of burlap, which receives in like manner another charge of material. This operation is repeated until a stack of batches of material held thus in sections of burlap is built up of sufficient height to fill the press. Sheet-iron plates may be substituted for the wooden slats.

In charging, the truck which is to support the charge is wheeled beneath the cookers or the "slush box." For this purpose a track is built from the press to the cookers. The cooked fish, by the manipulation of cocks and a movable spout, is permitted to flow upon the receptacle arranged for it. When the charge has been completed the truck with its burden is wheeled into the press. The pressure is applied until the maximum power of the press has been reached, or until no further amount of water and oil can be removed.

It is desirable that the material be pressed while still hot, as the water expressed contains glue in solution which on cooling tends to harden and clog up the filter.

When removed from the press the solids have been forced into hard cakes about an inch in thickness. These are shaken out of their burlap envelopes onto the floor, when they are ready for the driers.

The oil and water expressed from the scrap are permitted to run together to receiving vats. On standing and with the aid of heat, the oil rises to the surface and the fine sludge which has escaped the filter settles out. The oil is drawn off from the surface into a series of vats, where it is subjected to successive simple treatments for its purification. Suspended solids and occluded liquids are washed from it by bubbling steam through it, and occasionally it is "cut" with sulphuric acid to effect a clarification.

The residue pressed from the cooked fish may be saved to recover the glue which it contains, or it may be allowed to go to waste. The latter practice is the one generally adopted. For the preparation of glue it is thoroughly freed from solid matter and is then evaporated by steam coils to the desired concentration.

DRYING.

Of the several types of driers in use on the Pacific coast, there is only one employed in drying fish scrap from cannery waste which is at all comparable to the hot-air driers found in common use on the Atlantic coast. This is a drier of large size and capacity, the operation of which involves the principle of both direct and indirect heating. It is a rotary cylinder of iron mounted inside of an inclosing chamber of brickwork. Hot gases from crude petroleum burners are admitted to the chamber surrounding the cylinder and are drawn thence into the cylinder through apertures constructed at intervals in the walls. The scrap to be dried is admitted at the hot end of the cylinder and removed at the cool end, thus traveling with the current of air. From the cylinder it drops into an elevator and is carried therein directly to the bagging room. The current of gases through the drier is maintained by a rotary fan situated behind the drier. By means of this the gases drawn from the drier are forced through a chamber where they are washed free from suspended particles by means of a water spray. Thence they are driven through the fire box beneath the factory boilers. In this manner odors arising from the hot-air drier, and constituting, perhaps, the only objection to its use, are completely destroyed.

In the fertilizer plants of the Pacific coast the steam drier is employed most commonly, owing possibly to the simplicity of its installation and operation and to the fact that of all the driers it is most readily available in the desired capacities. It is not intended that the idea shall be conveyed by this statement that the steam drier inherently is more simply installed and operated. Such is not believed to be the case. But at present the hot-air driers advertised for sale and actually in use are large in both size and capacity and are unfit for the treatment of small amounts of material. The manufacturers have failed to meet, or perhaps to create, a demand for driers of small capacity, and for that reason the steam drier is in most common use. An additional advantage possessed by the steam drier is its simplicity of regulation. Overheating being impossible, it remains only to admit the steam and wait for the charge to dry. It can not be regarded as the most efficient or as the most economical except in cases where exhaust steam is employed.

The type of steam drier found in use in drying scrap from salmon waste usually is a horizontal cylinder provided with steam coils inside, or encircled by a steam jacket. For stirring, the cylinder is equipped with paddles revolving in it, or the cylinder itself is rotated on a horizontal axis.

A third type of drier, recently installed in a certain manufactory, is unique in that it makes use of the waste heat from the fires beneath the factory boilers. As this drier was designed by the operator from ideas suggested by his experience, and is not advertised for sale by the manufacturers of driers, the writer does not feel justified in publishing here the details of its construction. It should suffice to say that the drier is reported as being quite efficient and satisfactory, and the scrap coming from it is of a very high quality. Its lack of importance as a type is more than made up by its value as an illustration of what is possible in the enhancement of economy in a fish-rendering plant.

THE PRODUCTS.

CHARACTER OF SCRAP.

The scrap produced from salmon waste is of very high quality. For its value as fertilizer, it is open to criticism only on the score of its high content in oil. This amount of oil probably is not sufficient to prove a serious detriment to the soil nor, possibly, materially to retard the decomposition of the scrap within the soil. But it is disadvantageous in that it is so much inert material of no fertilizer value. The fact that the oil, of high value if extracted, here plays the rôle of a worthless diluent of a less valuable product, has no bearing on the value of the scrap as a fertilizer; instead, it concerns only the economy of the process by which the material is prepared. With regard to the bearing of the presence of oil in fertilizer materials on the value of those materials, attention should be called to the work of Skinner and Beattie,[1] of the Bureau of Soils, having to do with the value of city street sweepings for fertilizer purposes. To explain the poor manurial value of this material it was supposed that the presence therein of oil, dropped upon the streets by automobiles, prevented its decomposition, a supposition which became a conclusion when it was demonstrated that the same material, after treatment to remove the oils, showed a greatly enhanced manurial value. This oil is largely, if not entirely, mineral oil, which it is commonly known is much less readily decomposed than animal oils, such as fish oil. In this connection a comparison of the fertilizer values of oily and oilless fish scrap would be of distinct interest.[2]

CHEMICAL COMPOSITION OF SCRAP.

Samples of salmon scrap representative of the product of the various manufacturers were received at the laboratory in canvas sample sacks. These samples were ground to a powder that would pass a sieve of 16 apertures per linear inch. Samples of 2 grams each were then dried for about 5 hours in a vacuum drying oven at a temperature ranging between 75° and 85° C. The loss in weight was recorded as moisture. The same samples were then used for the determination of oil, which was extracted in a Knorr apparatus with ether. Great difficulty was experienced in removing all the moisture without the loss of oil. Nitrogen was determined by Mr. T. C. Trescott, of the Bureau of Chemistry, by the official method. For the determination of phosphoric acid the official gravimetric method was used. In Table VIII are reported the results of analyses of five samples of salmon scrap from an equal number of manufactories.

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[1] Circular 66, Bureau of Soils, U. S. Dept. Agr.

[2] Experiments recently made in these laboratories by Skinner and Lindemuth, in which the fertilizing value of oily and oilless fish scrap was compared, showed that the latter (extracted with ether) give pronouncedly better results than the former.

TABLE VIII.—*Analyses of fish scrap prepared from salmon cuttings.*

Number of sample.	Location of factory.	Description.	Nitrogen.	Phosphoric acid (P_2O_5).	Moisture.	Oils.[1]
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Klawack, Alaska	North Pacific Fishing & Trading Co. Sample from trial run with steam drier.	9.39	5.32	5.36	14.96
2	Anacortes, Wash	Robinson Fisheries Co. Dry scrap from steam drier.	8.26	7.91	5.21	17.36
3	....do	Russia Cement Co. Dry scrap from hot-air drier.	9.49	9.26	5.26	8.32
4	Seattle, Wash	Brandel Chemical Co. Dry scrap from steam drier.	8.76	7.00	3.91	20.02
5	Astoria, Oreg	DeForce Oil Works. Dry scrap from hot-air drier.	7.63	12.08	5.11	10.96

[1] More accurately, ether extract. This consists principally of oils.

COMPARISON WITH MENHADEN SCRAP.

For the sake of comparison between the salmon and menhaden scrap, the following table of analyses, made by E. G. Parker and J. R. Lindemuth, of the Bureau of Soils, is introduced here. This has been compiled from analyses made during 1912–13, and has been published in a former report.[1]

TABLE IX.—*Analyses of fish fertilizer prepared from menhaden scrap.*

Number of sample.	Location.	Description.	Nitrogen.	Phosphoric acid (P_2O_5).	Moisture.	Oils.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Kilmarnock Va	From Eubanks Tankard Co. Dry scrap (from 6 sacks).	8.93	6.17	6.48	5.91
2	Taft, Va	From Taft Fish Co. Dry scrap (sample of 525 tons).	8.96	7.75	6.18	6.81
3	Irvington, Va	From Carters Creek Fish Guano Co. Dry scrap, dried in hot-air and steam driers (from 1 sack). Fall product.	7.70	5.22	11.68	6.62
4	Cape Charles, Va	From Atlantic Fish & Oil Co. Dry scrap, ground (from 3 sacks).	9.29	6.12	7.86	5.38
5	....do	From Dennis Fish & Oil Co. Dust from grinders.	8.80	5.21	7.17	7.55
6	Beaufort, N. C	From Beaufort Fish-scrap & Oil Co. Dry scrap, hydraulic presses. Sample from heap.	8.22	5.95	6.13	8.57
7	Morehead City, N. C	From R. W. Taylor. Dry scrap from open heap.	8.49	5.95	9.12	8.23
8	....do	From Chas. S. Wallace. Scrap, dry, from hydraulic presses.	7.76	9.65	8.15	7.56
9	Lenoxville, N. C	From C. P. Dey. Ground scrap, sun-dried, from hydraulic presses. Sample from heap.	7.81	5.85	7.46	7.89
10	....do	From C. P. Dey. Scrap, dry, ground, hydraulic presses. Sample from heap.	8.29	9.00	7.00	5.40
	Average		8.43	6.69	7.72	6.99

[1] Bul. 2, U. S. Dept. of Agr., The Menhaden Fish Fertilizer Industry of the Atlantic Coast.

The salmon scrap has a lighter color and more pleasant odor than the menhaden scrap. This, again, possibly does not concern its fertilizing value, though there is a remote possibility that it may affect its demand in the trade. It is said that some agriculturists appraise the value of fertilizer materials by the disagreeableness and strength of their odor. On the contrary, it is a better established fact that considerable prejudice exists against fish scrap on the part of common carriers and the public in general because of its odor. Since nothing is to be lost and something is to be gained by reducing the disagreeable odors of fish fertilizer, the point mentioned is favorable to the salmon scrap. The better smell of the latter is due most probably in greatest measure to the fact that it is dried at moderate temperatures and is not scorched, as inevitably must happen in the hot-air driers as now operated on the Atlantic coast. It also is true that the menhaden scrap is dried in a stream of hot gases generated in a soft-coal fire; the soot from this doubtless contributes likewise to the dark color of the product.

Another point of difference between the salmon and menhaden scrap is introduced by the occasional acidulation of the latter. The addition of sulphuric acid to the scrap is practiced most generally to disinfect the undried but freshly cooked and warm "pomace," and to render it unfit as a breeding place for flies. This is resorted to, as a rule, only when the scrap is being produced at a rate greater than that at which it can be dried. The acidulation frequently is followed by drying. The addition of sulphuric acid to the scrap is supposed to be beneficial in that it "fixes the ammonia" and renders soluble the phosphoric acid of the calcium phosphate constituting the bones. While it induces a disintegration and pulverization of the scrap, and enables the producer to sell the bone phosphate present as soluble phosphoric acid, at the same time it acts as a diluent of slight, if any, fertilizer value, with no rating on a fertilizer basis.

In the foregoing comparison of scrap from salmon and menhaden, respectively, it is not intended to convey the idea that the menhaden scrap for fertilizer purposes is inferior to that from the salmon. It is believed that the ammonia and phosphate of the one is as valuable as that of the other.

FISH SCRAP AS CATTLE AND POULTRY FEED.

To discuss fish scrap from any point of view other than that of fertilizer, perhaps, is beyond the province of this report. It should be pointed out here, however, that with such fertilizer materials as dried blood, abattoir tankage of high grade, cottonseed meal, and fish scrap, it is better agricultural practice to feed these to stock, provided, of course, that all barnyard manures be conserved carefully, than to apply them direct to the soil. It can be taken as thoroughly well established that both the nitrogen and the phosphoric acid, after performing their rôle in the life processes of the adult animal, are eliminated. Then the high food value of these rich foods is utilized, and at the same time the fertilizing elements are still available for use on the growing crops. From the point of view of cattle and poultry feed, the salmon scrap must be considered superior to the menhaden. In the first place, the acidulated scrap is totally unfit for feeding purposes. Its use in that manner undoubtedly would result in disaster. And in smaller degree, the greater care expended in drying the salmon scrap makes it a more desirable article of food. In fact, when the nature of the raw material and the sanitary condition under which it is treated, obtaining in certain manufactories, are considered, it might almost be regarded as fit for man's consumption. It would be interesting to learn whether the oil remaining in the salmon scrap is of a more digestible nature than that in the menhaden scrap. No experimental data is at hand in substantiation of such belief; but such appears plausible when it is recalled that the salmon oil is light and sweet and partakes more nearly of the nature of the edible oils, while that from menhaden is dark, heavy, and viscous and has a disagreeable odor.

The subject of the suitability of fish scrap for cattle and poultry feed and the experiments performed relating thereto have been discussed in an earlier publication of this department and therefore will not be repeated here. In all of the experiments, records of which have come to the attention of the writer, the results have been affirmative and of such a nature as to justify the further exploitation of this food material for that purpose. The reader interested in this phase of the subject is referred to Bulletin 2, United States Department of Agriculture, The Menhaden Fish Fertilizer Industry of the Atlantic Coast.

OIL.

The literature contains little having to do with salmon oil. The amount actually produced, 286,000 gallons, is too small to give it any great importance in the industries. It is rated, however, as a high-grade fish oil. The price which it brings in the market, 30 cents a gallon, against 23 cents for menhaden oil, is sufficient evidence of that fact. There is no reason to doubt that it is destined to play an important part as an animal oil when the salmon-scrap industry is fully developed and there is enough oil available to make its study and exploitation profitable.

In the absence of more detailed information concerning the physical and chemical properties of salmon oil, it must suffice to say that it is merely a high-grade fish oil. The crude salmon oil is lighter in color than, perhaps, the refined menhaden. Its properties, as now understood, adapt it to the uses to which menhaden oil successfully has been applied, conspicuous among which is its utilization as a lubricant, and especially in the paint and enamel industries.[1]

GLUE.

Fish glue made from salmon is regarded as low grade and of proportionately slight value. In this particular it differs markedly from that prepared from cod skins. It is used with success in the preparation of sizings and allied materials.

METHODS PROPOSED FOR THE TREATMENT OF SALMON CANNERY WASTE ON A LARGE SCALE.

In the treatment of salmon cannery waste two methods immediately suggest themselves: (1) Treatment in large units, and (2) in small units. The former at first glance appears the more desirable, as it generally is understood that large-scale manufacturing operations are more economical in both labor and equipment than those conducted on a small scale. And it is the large-unit plan that now is in operation; without exception, all the salmon scrap at present produced is the product of the large-unit plants. The foregoing description, then, of the present method employed in rendering salmon waste applies in a large measure to that of a proposed central rendering plant. In fact, it may be argued that it is not wise to diverge from the methods now in vogue as they are the only ones which have been applied with any commercial success whatever.

THE CENTRAL RENDERING STATION.

The failures in the operation of centrally located rendering plants have been as numerous as and far more conspicuous than the successes. The causes operating to bring about these failures, it appears at this distance, were manyfold. Speaking of the failures collectively and not as individuals, it is evident that over capitalization and extravagance in expenditure for equipment, the failure of equipment to yield its expected performance, errors in the location of the plant, and general inexperience all contributed.

The plan has inherent faults. These are twofold: The high expense involved in hauling the raw material to the plant and the lack of machinery which would make the rendering process continuous, automatic, and economical. A further disadvantage, applying to both proposed methods but in greater degree perhaps to that of the central plant, is the shortness of the season during which the plant would be in operation. In this discussion the adoption of the plan is opposed further on the ground of its general failure to meet the demands of the problem.

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[1] For a brief discussion of menhaden oil see ibid., p. 46 et seq.

In considering the first objection it becomes evident that the larger the rendering plant the larger must be the equipment in tugs and scows and the longer the haul. The irregularity with which the canneries operate and the vagaries of the weather introduce elements of uncertainty which make it difficult to calculate the probable limits within which the waste profitably can be collected.

COLLECTING THE MATERIAL.

Loading the waste.—Three methods are available for loading the cannery waste: (1) By means of a scow under the dock at each cannery; (2) by means of a storage bin under the dock at each cannery; (3) by means of a storage bin on the dock at each cannery.

(1) The first method is objectionable in that the outlay for scows would be too great. Two would be required for each cannery, one receiving a load while the other was being unloaded. A scow 30 by 16 feet in dimensions would cost about $300. The investment in these would be $600 for each cannery tended. Smaller scows designed to hold the maximum daily output in waste of the cannery could be built, perhaps, for a smaller sum, but their usefulness for other purposes would be restricted.

A contract between a cannery and a central rendering station most probably would specify a daily removal of waste. Certainly there would be days when the yield in cuttings would be small, far too small to fill a scow. Yet under the contract and this system of collecting it would be necessary to remove the partially loaded scow and transport it to the rendering station, or else carry it away for emptying. And even if the daily collection were not required, in warm weather a frequent collection would be absolutely essential and easily might result in the enforced transportation of but partially filled scows.

The greatest advantage to accrue from this method would be that the waste could be sluiced directly from the cannery floor or cleaning tables into the scow and would be ready for transportation without any further handling whatever. On the other hand, an occasional cannery would be found to have been built too close to the surface of the water to admit of the loading of a scow in this manner.

In a foregoing paragraph has been described the method of loading, by a simple system of conveyors, when the cannery floor is too low to admit of the scow's being placed beneath. Where such an apparatus has to be installed and operated, the advantages of the direct loading into a scow disappear.

(2) Under ideal conditions the collection of the waste in storage bins placed beneath the cannery floor or dock is the most economical. The conditions considered ideal are that the cannery floor or dock shall be of such a height that the scow to be loaded can be placed

beneath the storage bins so that it can be done entirely by gravity. That it be loaded thus by gravity is a virtual necessity, as pitching the material from the bin into the scow by manual labor would be too expensive. But it not often is found to be possible to load the scow by gravity at high tides, and therein lies the chief objection to the method.

The bin so placed would be loaded by sluicing the cuttings directly into it. This would entail no extra labor over that of the present practice. The bin should be built with a bottom sloping toward an opening through which the waste could be admitted as desired into the scow. In the sides of the bin, sections of close-mesh wire netting could be inserted, if desired, to permit the excess water to drain away; or, since the cutings are heavy and will sink, the water could be permitted to run over the top edges of the bin. The latter is undesirable as entailing an extra and unnecessary weight on the bin.

An additional advantage of any system involving the use of storage bins is that, under favorable conditions, a large-capacity scow can make the circuit of the canneries tended, collecting what material has accumulated since the last round, whether that amount be large or small.

(3) Storage bins placed on the dock at each cannery would possess the advantage that they could be unloaded by gravity at any tide. The chief objection to them would be that they would have to be loaded mechanically. The waste would have to be brought from beneath the cannery floor, by conveyor, outward and upward, to the bins, involving the expense for installation and operation of the conveyors. As this is the method which, under the conditions usually obtaining, is the only one under absolute mechanical control and therefore the only reliable one, it perhaps is the most desirable method of the three. On the other hand, there is no reason why the method to be employed at each cannery can not be determined by the conditions peculiar to that cannery. No hard and fast rule need be applied.

Tugs.—The number of tugs required to collect the raw material from the various canneries would be determined by conditions such as the number of canneries tended, their output in waste, the system of collecting, the capacity of the scows employed, and especially the position of the canneries with respect to each other and the rendering station. In elaboration of the last-named condition it should be pointed out further that if the canneries were situated in such a way that the direct course from the farthest one to the station lay past the others, one tug and scow or scows of sufficient capacity could collect the load from a number of canneries on one trip.

RENDERING APPARATUS.

The equipment and operation of the large-scale rendering stations now in successful operation have been described compositely in foregoing paragraphs. A strictly conservative procedure would be to adhere to demonstrated methods. However, since these methods once were in universal use on the Atlantic coast and now have been discarded almost universally to make way for new methods, a discussion of new methods, and even a recommendation of their cautious adoption may be justified.

The only process which has been applied with any success to the rendering of this class of material on the Pacific coast, it has been shown, is discontinuous. The apparatus required by this process may be installed and operated in small units, necessitating a multiplication of the labor involved, or in large units, involving more labor than the small units, of course, but not proportionately. Since the material to be treated is secured in irregular and uncertain amounts, a number of small units would afford more of the required elasticity than an equivalent number of large units, but the cost of labor required to operate such a number of small units soon would become prohibitive. So, by nature, this apparatus offers serious objections to its adoption in the large-capacity plants.

The continuous and automatic machines for cooking, pressing, and drying in use in the fish-rendering industry of the Atlantic coast should lend themselves readily to adaptation to that industry on the Pacific coast. These make possible the cooking, pressing, drying, and intermediate handling of the fish entirely by machinery, with a high efficiency and minimum expenditure of labor. The unloading is done by elevators, which deposit the fish in storage bins, from which they are fed into continuous steam cookers, long tubular chambers through which the fish are moved by a rotating screw, being played upon by jets of steam. Thence they are transported by conveyors, into which they are fed, to the power presses. These are steel-slatted cones, through which the cooked fish are forced by a rotating screw. As they move toward, and before they can pass out of, the small end of the cone, they are squeezed into a very small compass. This pressure rids them of the greater portion of their water and oil. From the press they are conveyed, again entirely automatically, into a direct-heat, rotary, hot-air drier.

A plant designed for the treatment of 100 tons of cannery waste per day and equipped with the automatic machinery complete would cost about $35,000. This estimate [1] is based on the following items.

[1] The itemized statement of the cost of equipment and plant is made possible through the courtesy of Mr. Philip Renneburg and Mr. P. Burgess, of Baltimore, Md.

Two 66 inches by 16 feet, 100-pound pressure, return tubular brick set boilers, 100 horsepower each, complete with independent stacks of No. 10 metal, with castings and fittings arranged for full flush front setting	$1,650
One 20-horsepower vertical engine, complete with all fittings (for elevator)	230
One 9 by 12, 20-horsepower, horizontal center-crank engine, complete with all fittings (for raw box transmission)	275
One 10 by 12, 25-horsepower, horizontal center-crank engine, complete with all fittings (for cooker and near-by transmission)	315
One 11 by 13, 35-horsepower, horizontal center-crank engine, complete with all fittings (to operate press)	355
One 10 by 12, 25-horsepower, horizontal center-crank engine, complete with all fittings (for drier and surrounding transmission)	315
One 150-light, 16-candlepower, vertical, electric-light engine, cased in, directly connected automatic lubricator and generator, with switchboard	725
One marine leg fish elevator, with measuring machine and all necessary transmission complete for elevating fish from scow to factory	1,650
Complete raw box transmission, consisting of all chains, attachments, buckets, sprockets, gears, shafts, and clutches, complete	1,500
One 17 inches diameter by 40 feet long, spiral worm steam cooker, complete, with driving sprockets	1,200
One 12-foot, all-steel, continuous screw press	3,500
One 5 feet 6 inches diameter by 40 feet long, two-bearing drier, with hopper, castings, blower fan, blower piping, and Jones underfeed stoker	2,500
Balance of and completing factory transmission, including pipe work in connection with boilers, engines, and pumps	2,500
One 1,200-barrel steel-plate, oil-storage tank	1,000
Incidentals, such as boiler feed pump, oil pump for transmitting oil to tanks, general wash-down pump, fish and coal measuring tubs, perforated piping system in connection with oil tanks, etc	1,500
Total	19,215

In addition to this, there will be an outlay for buildings, brickwork for the drier, and all foundations for buildings, boilers, engines, machines, and tanks. This cost is difficult to estimate, as it will be determined largely by local conditions and the factory site, but probably will approximate that for the equipment, bringing the total for plant and equipment to the figure mentioned above. In addition to this cost again would be added the items expended for tugs and scows.

Superficially there seems to be no reason whatever why the automatic and continuous cooker in its present form should not be entirely applicable to salmon cuttings. The rate at which the material is passed through, and therefore the length of time during which it is being subjected to the cooking action of the steam, are regulated with ease. Thus the degree of cooking is under complete control. It has been demonstrated that cooking under pressure is not essential. However, even with the continuous cooker a certain degree of pressure can be maintained, if desired, by the correct modification of the cooker.

The press in use in the menhaden factories has been designed for expressing the cooked menhaden. As that material is markedly different from salmon waste, there is no reason to suppose that the press efficacious with the former will be so with the latter. However, there is every reason to believe that the press so useful with the one can be modified so that it can meet the demands of the other. This is not a necessary conclusion, since the limits of usefulness of this form of press may lie between the requirements of menhaden on the one hand and of salmon cuttings on the other. As indicated above, this is not believed to be the case. In this connection it should be emphasized that, in view of the fact that the screw press has never received a thorough demonstration in the salmon-scrap industry, before other plants are equipped with it it should be made to conform to the demands of that industry. This can be done only by thorough experimentation by those familiar with the press and the nature of the material to be pressed.

The rotary, direct-heat drier probably should be the most economical type at present available. Its present methods of operation can not be so considered. In construction, it is a sheet-iron cylinder, about 40 feet in length and 5 feet 6 inches in diameter. It is mounted, at a slight angle out of the horizontal, on roller bearings which support its weight and on which it revolves. The material to be dried is fed into the upper end and falls out at the lower. Also into the higher end is blown a stream of hot gases, generated by forcing air from a blower through the firebox of a furnace. The wet scrap falls directly into this stream of hot gases and by it is assisted through the drier. It also is lifted and let fall repeatedly by the rotation of the cylinder.

Such a drier yields about 45 tons of dry scrap per day. In practice the moisture content of the material (fish-pomace) is reduced from 55 or 60 per cent to 7 per cent, at a closely estimated cost of 50 cents per dry ton. This cost is based on the following items: To heat the drier, approximately $3\frac{1}{2}$ tons of soft coal is required, while an additional $1\frac{1}{2}$ tons is consumed in supplying the power for the rotation of the drier and the operation of the conveyors. One skilled laborer is required to operate the drier and two unskilled laborers to tend the drier furnace and the boilers.

For the most efficient utilization of a stream of drying gases, theory demands that it shall flow from the opposite direction over and through the stream of material being dried. Thus the hottest and driest gases are brought into contact with the hottest and driest part of the material being dried, and the coolest and wettest gases with the coolest and wettest material. In this way the maximum moisture-absorbing capacity of the gases is made use of and their heat entirely is utilized. To make such a procedure possible, a lower initial temperature of the gases would be necessary to prevent the ignition of the hot, dry material; and it is probable that a longer drier and a more prolonged intermixture of the material and the drying agent would be necessary. A point might be reached where the energy necessary to rotate the drier for the increased length of time would cost more than the heat units conserved would justify. This is a matter which could be determined by experimentation.

In a drier of the above type use is made both of the heat units and of the drying action of a current of gas. The matter is entirely different from the evaporation of water in a closed vessel, where the evaporation of each unit weight or volume of water is accompanied by the absorption of a definite amount of heat. To be sure, all evaporation is so accompanied. But it is remembered that water is evaporated by a current of air without the application of artificial heat. And, too, the hotter and drier the stream of air the more rapid the evaporation. In the hot-air drier this combined action is made of use.

The fish-fertilizer industry as developed on the Atlantic coast has found the above-described continuous and automatic apparatus the most satisfactory for meeting the demands of that industry. On the basis of that verdict one is inclined to believe that this machinery most advantageously could be applied to the large-scale rendering of salmon-cannery waste, provided the proper modifications were introduced to make it entirely adapted to that sort of material. We do not regard the past failures of this machinery as significant of any fundamental unfitness, but rather of a lack of attention given the requirements of the new material to which it is applied. In the present stage of knowledge of the subject it appears that the continuous-process machinery conforms most nearly to the ideal equipment.

Rendering apparatus of various other forms are to be had. Many of these forms have been applied with success to the rendering of garbage and tankage. Some are designed with a view especially to the suppression of all disagreeable odors, others to the recovery of a larger percentage of the oils present. The latter usually involve the use of petrol or gasoline as the extracting agent, which effects a more complete recovery of the oils. This may obviate the necessity both of a press and a drier, the cooking, drying, and extracting being accomplished in one container, the retort. Theoretically, such processes for the recovery of oil are most nearly ideal. Whether they can be applied successfully to the rendering of fish, viewed from the commercial standpoint, remains to be demonstrated in this country.

OBJECTIONS TO THE CENTRAL RENDERING STATION.

SHORTNESS OF SEASON.

A serious difficulty in the way of making a commercial success of the central rendering station is the shortness of the season during which the plant would be in operation. This would be even shorter than that during which the canneries would be in operation, as both preceding and following the actual canning of fish there is a period when allied work is pursued. Furthermore, the rendering plant would have to be in readiness to handle whatever material the management had contracted for (certainly to be the entire output of waste of the cannery contracted with) whether it became available in large or small amounts. The result would be that for about nine months of the year the plant would be closed up; and for a considerable portion of the remaining three, while being held in readiness to operate, it still would be idle. This objection is entirely valid from the point of view of output, but not necessarily so from that of profit or investment. Money is invested in such enterprises, not because of their output in product, but because of the profits accruing. If the profits of the short season's operations represent an adequate interest on the investment, then the expenditures for plant are justified and objections on the score of shortness of operating season are eliminated. Aside from the inconvenience of reorganizing annually the corps of employees, the period of inactivity may be considered a benefit, as affording the management opportunity for other pursuit.

The inactivity of the plant during the operating season is a more serious obstacle to the success of the undertaking. There would be periods when no material was being delivered to the plant when it and its corps of laborers would be held in readiness for immediate operation. This would involve an expenditure of money for wages and of fuel for maintaining heat in the boilers from which there would be no returns.

A part of the equipment of such a rendering plant, the tugs and scows, it should be possible to keep employed profitably during the winter months. Whether this could be done would depend somewhat on the location of the plant and to a larger extent on the design of the tugs and scows.

In this connection it should be pointed out that the equipment provided for the treatment of cannery waste could be applied during several months of the year, when fish refuse is not available, to the treatment of kelp for the preparation of fertilizer. This topic is considered more fully in a subsequent chapter.

GENERAL FAILURE OF THE CENTRAL RENDERING STATION TO MEET THE DEMANDS OF THE PROBLEM.

Our problem being to devise a scheme whereby the valuable materials produced as waste in the canning of salmon in particular and the dressing of fish in general may be saved, any plan which provides for the conservation of only a portion of this must be rejected as inadequate. Therein lies a vital objection to the central rendering station idea—that at best it can render the waste only from those fish-cleaning establishments which happen to be grouped together in close enough proximity to make the collection of the waste economically possible. In the Columbia River region this plan as now actually applied results in the utilization of 800 tons from a total of 4,000 tons. In the Puget Sound region four of these stations conserve a total of 15,500 tons, out of a total of 38,750 tons. The scheme as suggested for ideal conditions, as well as when actually applied, it is reiterated, falls far short of meeting the demands of the problem.

THE SMALL BY-PRODUCTS PLANT OPERATED AS AN INTEGRAL PART OF THE CANNERY.

As the only alternative to the central rendering station, the suggestion is offered of a by-products plant operated as an intimate part of the cannery. This would be a small-unit plant of low capacity, just sufficient to treat the output in waste of the cannery of which it forms a part.

EQUIPMENT.

For equipment the old-fashioned, unimproved retort cooker and hydraulic press are recommended, not because they are regarded as ideal, but because they constitute the only apparatus which the writer has seen in successful operation on a small scale. It has been demonstrated, and is being demonstrated daily, that this form of apparatus will render salmon cuttings, affording a good grade of scrap and a fair yield of oil. The demonstration has not been confined to large-scale operations, but has been attempted on a small scale as a strictly by-products plant, with satisfactory preliminary results.

The equipment, as has been pointed out in a foregoing paragraph, consists essentially of retort cookers, a hydraulic press, and a drier of suitable form, heated by steam or hot air, as the experience and wisdom of the designer indicate. From a "one-line" cannery, or one with a maximum capacity of 900 cases per day of 12 hours, would be obtained a maximum of 18 tons of waste. This figure is based on the estimate of 40 pounds waste per case. The by-products plant possibly should have sufficient capacity to render this volume of waste in a run of six hours; that is, a capacity of 6,000 pounds per hour. Such a high capacity is suggested in order that it may be insured that the steam required for cooking can be supplied by the cannery boilers. It is believed that the requisite steam surely can be withdrawn from these for a period of 6 hours out of the 24. This appears especially probable in view of the fact that the cannery is shut down almost invariably during some period of the day, and that while still running a varying demand is made on the steam capacity of the boilers. As has been observed in a foregoing paragraph, the dressing force may be at work and the machinery which they tend may be in operation when the steam boxes and cooking retorts, requiring a large amount of steam, are idle. If it can be shown that sufficient steam is available to operate the cooker for a longer period than the 6 hours suggested, the capacity of the rendering apparatus, and perhaps its cost, can be reduced proportionately.

In addition to the three above-mentioned pieces of apparatus, there would be required conveyors, a storage bin to receive the day's supply of raw materials, vats in which to recover the oils and storage capacity for the oils produced, and a house sufficiently large to inclose the apparatus and provide room for bagging and storing the output of dry scrap.

Unless the conditions are such that the waste can be sluiced directly, by gravity, into the storage bin, a conveyor must be provided to carry this from beneath the floor of the fish-cleaning house. The structure of this will depend on the angle at which it is required to work. Thus, if the conditions are such that a horizontal conveyor can be operated, all that is needed is a water-tight trough through which pass blocks or boards of wood, suitably attached to and actuated by the movement of a chain belt, to direct the flow of the waste and the water in which it is immersed. The cuttings from the "iron chink" may be made to fall into a hopper placed beneath, which deposits the waste upon the conveyor; likewise that from the other cleaning operations may be directed, in any suitable manner, upon the conveyor. From the storage bin the material is to be lifted by elevator and fed into the retorts. Therefore the bin should be constructed with a sloping bottom so that the last of the material contained therein will feed automatically into the conveyor. Strainers of woven wire should be inserted in the sides of the bin to permit the excess water to drain away. To accommodate the day's output in waste the bin must have a capacity of about 20 tons.

Two retorts of the upright, cylindrical form should be provided of about 5 tons capacity each, two offering the advantage over one of greater elasticity of operation. The daily output in waste of a one-line cannery, amounting to about 18 tons, could be rendered by the two retorts of the capacity suggested in two cookings each.

Whether the retorts should be of open type or closed to make possible cooking under pressure is debatable, as equally satisfactory results apparently are had from both types.

Beneath the retorts a "slush box," or bin, should be constructed, of sufficient capacity to hold the cooked fish from at least one retort, and provided with steam coils to keep its contents hot. As the material is to be drawn off from this onto frames for the press, it should be provided with suitable gate valves for that purpose and should be built at such a height that the material could be run onto the frames directly by gravity.

For pressing, at present the method previously described, involving the use of "hop cloth" envelopes for the material to be pressed and hydraulic power ("rack and cloth" press), must be recommended. This is slow and laborious, but effects an efficient separation; and at present it has the distinct advantage over all other methods of pressing salmon of having been demonstrated as entirely feasible.

In actual practice at least two men are required to operate the press. This number probably could not be reduced, as the placing of the frames and especially of the "hop-cloth" squares scarcely could be done by one man, as is true also of the removal of these after the pressing has been finished. An additional objection to this method of pressing is the difficulty of cleaning the frames and cloths. During the pressing they become covered with the finely divided cooked fish. This spoils readily unless removed. To clean them by hand, as now practiced, is a tedious method which certainly could be improved.

Adhering, again, to demonstrated forms of apparatus, the steam drier must be suggested (Pl. VI, fig. 1). A form employed with success in one small cannery by-products plant has the shape of a drum, 6 feet in diameter and 2½ feet deep. It is steam jacketed and therefore must be insulated. For heating it, steam under 20 pounds pressure is requisite. Paddles for stirring are attached to a vertical shaft which is actuated through suitable gearings by a small steam engine. A rotary fan serves to remove the moisture-charged air. An opening in the top is designed for filling, with another near the bottom for emptying. The latter operation is accomplished automatically when the paddles are revolved with the lower door open. The drier of the above dimensions receives a charge of 1,500 pounds of wet material. With this apparatus a small steam engine would be required. One of 15-horsepower capacity has been found sufficient to operate the drier and the conveyors of the plant.

As this drier has a rated capacity of only 1,500 pounds of wet material, and as it requires two hours in which to effect the drying, which is equivalent to 750 pounds per hour, its usefulness is limited to a plant of small capacity. To provide drying capacity for the maximum possible daily output of raw materials from a "one-line" cannery, amounting to 27,000 pounds, at least four of those would be required, a number which scarcely could be operated economically. This estimate is based on the supposition that the driers will be operated only six hours per day.

There are other forms of steam driers of more or less desirable design which could be adapted to the small-scale drying of scrap. However, no steam drier should be considered which does not provide for evaporation under vacuum or for the removal, at frequent intervals or continuously, of the moisture-saturated air. The efficiency of any other form necessarily must be low.

We believe that there are other possible forms of apparatus which could be operated more economically, and others again which would yield a higher efficiency, but these lack demonstration in actual practice and for the sake of conservativeness and fairness to all concerned are not recommended here. We have in mind, in this connection, continuous mechanical cookers and screw presses, of small capacities, capable of rendering in about 6 hours the waste resulting from a 12-hour run of the cannery. For a "one-line" cannery, packing 900 cases per day of 12 hours, it has been seen this would be 18 tons for the day, or 6,000 pounds per hour (900 cases, 40 pounds per case, rendered in 6 hours). To operate with these, a suitable drier, preferably continuous and automatic, must be installed. For this purpose a hot-air drier is recommended, one designed to utilize the waste heat from the boiler fires, or, more simply, a rotary, direct-heat, cylindrical drier, heated with petroleum burners. This, in order to keep pace with the cooker and press, would be required to have the capacity of about 1,800 pounds wet or 900 pounds dry scrap per hour. The latter figure is obtained by taking 15 per cent of the weight of the original raw cuttings as its equivalent in dry scrap. In the press the moisture of this would be reduced to about 50 per cent. Requisite mechanical conveyors for transporting the raw materials from the storage bin to the cooker and from one machine to another would make the entire operation automatic and would reduce the labor required to a minimum.

Another form of apparatus for small-unit rendering plants is the one-operation apparatus, referred to in a foregoing paragraph, which prescribes the cooking of the material to be rendered in a closed retort, under pressure of steam and with revolving knives or macerators, the withdrawal of the water and oil which rises to the surface, and the evaporation to dryness, under vacuum, of the solids remaining. Heat for both cooking and desiccation is supplied by steam. As the entire operation is performed in a closed vessel and as all gases and liquids are conducted out of the building in pipes, the process is inodorous. While it is automatic it is discontinuous. Low initial expenditure for equipment and economy in operation are claimed for the process by its exploiters. From a priori considerations there appears no reason why the process should not fulfill its promised performance, though it does appear a little doubtful whether the oils can be liberated sufficiently by maceration and washing without bringing the material to such a fine state of subdivision that a great deal would be lost in the water drawn off with the oil, or too long a time would be required to permit the solids to separate by settling. At present, this apparatus has received no trial in the actual commercial rendering of salmon cuttings, and a positive opinion concerning it is not justified.

A comparison of the reports of analyses of salmon and menhaden scrap, respectively, as reported in this paper on page 33, will show that the amount of oil remaining in the salmon scrap is much higher than that in the menhaden. While this may be due to the difference in the respective methods of drying the two (an explanation further suggested by the lower oil content of the two samples of salmon scrap dried in hot-air driers and involving the supposition that oils are volatilized in drying), it also may be due to the fact that the oils are not so easily recovered from salmon as from menhaden. This constitutes an additional reason why some method, if feasible, should be adopted whereby a more complete recovery of the oil is possible. The limits of the press easily are reached.

With the abandonment of the press, the adoption of a system involving the use of an extractive recommends itself. The extraction of the oils with gasoline theoretically should be quantitative, and the exploiters of processes based on the use of this extractive claim a very high efficiency. The method consists of cooking the material to be rendered in closed retorts with steam. At the end of the cooking the water in the material is evaporated under vacuum. When the evaporation is complete, the dry residue is washed thoroughly with gasoline, which removes all but about 1 per cent (more accurately, 1 per cent of the weight of the dry scrap, according to the claims made for the process) of the oils present. The gasoline extract is drawn off from the scrap and distilled. The oil remains as a residuum, and the evaporated gasoline is condensed and recovered. It is reported that there is but a slight loss in gasoline. An additional advantage of the method is that all of the nitrogenous constituents of the fish are saved, while in the other methods there is an indefinite loss due to the solubility of certain of these in the water drawn off of or expressed from the cooked fish and thrown away. A further modification of the system, known as the Cobbwell system, is based on cooking in oil the material to be rendered, the oil being obtained from previous extractions. After cooking, the excess of oil may be drawn off, when the remainder is extracted with gasoline.

The output in scrap of the by-products department of the average cannery, one putting up 50,000 cases, would be not more than 115 tons for the season, or, on the basis of 900 cases for the maximum daily pack, not more than 5,000 pounds per day. For bagging this small amount of scrap no special apparatus need be installed, though bagging would be facilitated if the scrap were elevated to and delivered into a storage bin from the bottom of which it could be drawn off into sacks by the bagger as desired. As a sack is made to hold 100 pounds, 50 bags would be required for the maximum daily output. Adequate floor space must be available for spreading the scrap for cooling when first removed from the drier. Vats for receiving and for the subsequent treatment of the oil and water removed by pressing must be provided. These should be on a level below that of the press so that the oil and water can be delivered into them by gravity; or if this arrangement is not convenient, a pump should be provided for raising the liquids to the vats. In either case, some sort of vat must be constructed beneath the presses as a temporary receptacle for these.

To separate the water and oil, the mixture should be allowed to stand in a vat, being kept hot by steam coils. The oil rising to the surface should be permitted to flow over a weir into a second vat, while the water is drawn off through a lower opening. If found desirable, an arrangement may be provided for drawing off likewise the finely divided solids which settle to the bottom of the vat. For effecting a simple purification of the oil, the second vat should be equipped with steam pipes with perforations so that steam may be bubbled into the oil. Then it may be drawn off into a tank for storage, or directly into barrels for shipment. The total output in oil from the suggested plant would not be more than 20,000 gallons, assuming a yield of 25 gallons per ton of raw material rendered; or, 450 gallons as the maximum daily output.

COST.

APPARATUS.

While the cost of a plant will be determined, of course, by a number of interdependent circumstances, the following estimates will serve to convey some idea of the outlay required to equip a by-products plant for a one-line cannery. Vats of sheet iron of about 5 tons capacity are obtainable for $350 each. A press may be obtained for as little as $300, or $800 may be paid for it, depending on the nature of the press. Driers of the type mentioned cost not more than $600. For a capacity of 4,500 pounds per six hours, six of these would be required. For the purchase of conveyors and other sorts of equipment, such as pipes, etc., and their installation, it is estimated that $1,000 would be adequate. A building 20 feet by 50 feet doubtless would be large enough, which could be erected, perhaps, for about $2,000. In the following table the probable costs are itemized:

Costs of apparatus.

Retorts, 2, at $350	$700
Press	550
Driers, 2, at $600	1,200
Engine to operate driers	350
Incidentals	1,000
House	2,000
Total	5,800

OPERATING EXPENSES.

As the hypothetical plant is to be run at night, or at times when the cannery boilers are not carrying their maximum load, it is probable that an extra engineer and fireman would have to be employed. In addition to these, three other laborers should suffice. At $100 per month for this engineer and $75 each for the fireman and the three laborers, the outlay for labor for the two months would be $800.

To sack 115 tons dry scrap, putting 100 pounds in a sack, 2,300 sacks would be required. These, at 10 cents each (a price which includes the cost of the necessary string also), would amount to $230.

From 750 tons of raw material, the amount rendered per season, about 19,000 gallons of oil would be produced. To contain this volume 380 barrels, of 50 gallons capacity, would be necessary. These are purchasable at $1.85 each, necessitating a maximum outlay of about $700 for barrels.

To render garbage, it is stated, 25 pounds of bituminous coal is required per ton of garbage rendered. On this basis, to render 750 tons of cannery waste, 9.5 tons of coal would be required. This would cost, on the Alaska coast, $76 (9.5 tons at $8 per ton). An additional outlay for coal, for estimating which reliable data are lacking, would be occasioned by the operation of conveyors and driers.

An additional estimate, of doubtful value, of the amount of coal necessary to dry the cooked scrap can be secured by considering the actual amount of water to be evaporated in drying this and the quantity of heat necessary to evaporate a given quantity of water. The wet material coming from the presses consists of about 50 per cent of water and 50 per cent of solids. To prepare 120 tons of dry scrap, an equal weight of water must be evaporated. To evaporate this in a closed vessel would require 12 tons of coal, on the basis of 1 part of coal to 10 of water. This would cost $96.

A further item which must be considered in Alaska is freight charges on products.

The running expenses, then, may be put as follows:

Interest on investment, $6,000, at 10 per cent	$600
Depreciation, at 10 per cent	600
Wages, 1 man at $100, 4 at $75 per month, 2 months	800
Sacks, 2,300, at 10 cents	230
Barrels, 380, at $1.85	700
Coal for rendering, 10 tons, at $8	80
Coal for drying, 12 tons, at $8	96
Freight (from Alaska) on 120 tons scrap at $4	480
Freight (from Alaska) on 380 barrels oil, 75 tons, at $4	300
Total	3, 886

The proceeds may be estimated as follows:

Scrap, 115 tons, at $40	$4, 600
Oil, 19,000 gallons, at 30 cents	5, 700
Total proceeds	10, 300
Total expenses	3, 886
Balance	6, 414

According to the above estimate $6,414 are put down as profit. More strictly this should be regarded as the working margin of income over expenses. As the conditions imposed are more severe than those probably to be encountered, it is believed that this estimate is conservative. This belief is strengthened by the fact that the estimates on the same general basis, prepared by an experienced manufacturer of fish scrap from this class of material, is 50 per cent lower than the above as concerns the running expenses and 20 per cent lower with respect to equipment. Thus, a larger capacity is prescribed than probably would be necessary, and a much shorter working day than would be required in actual practice.

In operating the supposed by-products plant, the labor problem is regarded by those packers who operate in Alaska as a serious matter. This may be the case in western Alaska, where it may be necessary to employ the force for the by-products plant before leaving the States and to carry them on the pay roll until they return in the fall; but in the other parts of Alaska it is difficult to see how the problem of securing three or four additional laborers could be serious. While it is probable that in the busiest part of the season every member of the cannery force is employed, at other times there should be a sufficient number of men temporarily idle to do all the work required in the by-products plant. An additional force, if necessary, could be secured for the rush season.

ADVANTAGES OF THE BY-PRODUCTS PLANT.

FINANCIAL.

There are three decided advantages possessed by this system of disposing of cannery waste. The first and most striking is that of the elimination of all costs of collecting. With these disappear likewise the worry incident to the numerous elements of uncertainty involved in collecting. Thus at once are eliminated tugs and scows and their crews. The expense of collecting is but a trifle more than that of disposal by dumping through the cannery floor, and is decidedly cheaper than the method resorted to by some canneries.

As the producer and consumer of the raw materials are one and the same, the conflict between the interests of the two disappears. Contracts working a hardship upon the one or the other are an objectionable feature of the central rendering station plan as actually practiced.

With a strictly by-products plant, overhead charges disappear. The cannery already has its clerical force and its sales and purchasing departments, which, without any increase in their force, are quite able to handle the slight additional labor incident to the by-products plant. Likewise it has the assistance of experienced foremen and mechanicians regularly attached to the cannery force, and the use of the supplementary equipment, such as machine shops, of the cannery. Likewise, the docks, and frequently the unused floor space of the cannery, can serve to cut down the initial expenditures.

OTHER ADVANTAGES.

The advantages other than monetary to accrue from the preservation of the cannery waste perhaps equal the financial advantages. The main item gained, of course, is the greatly enhanced sanitary condition of the cannery and its environs. To discuss here the moral effect of the most economical utilization of the fish now given to the packers "for the taking" on the residents of the State with which the packers come into important contact, perhaps, is too far afield for the purposes of this bulletin. The suggestion of such an advantage is made for what it is worth.

THE PRODUCTION OF A MIXED FERTILIZER FROM FISH SCRAP AND KELP.

KELPS.

Since the shortness of the season during which the proposed central rendering station would be in operation has been suggested as a great obstacle in the way of the commercial success of that project, it becomes highly desirable to find some other use to which the equipment of the plant could be applied during seasons when no cannery waste would be available for rendering. All along the Pacific coast from Mexico to Bering Sea there is a vast quantity of fertilizer materials, the giant kelps, whose values are recoverable by a process similar in part to that prescribed for the conversion of cannery waste into fertilizer, and adequate supplies of these are found near certain of the centers of the salmon-canning industry. It originally was supposed that the rendering of the cannery waste could be made to serve as an auxiliary operation to the treatment of kelp. After investigation it appears more probable that it would be found necessary to make the curing of kelp supplementary to the rendering of fish waste, since the apparatus required for the latter is much more elaborate than that for the former.

The term "kelp," formerly applied to the ashes of seaweeds, now has come to mean any of the brown marine algæ. In general use its meaning has become restricted to the large and conspicuous sea algæ of the Pacific coast. The so-called giant kelps of the Pacific coast may be defined as four species of the marine algæ, whose botanical names are *Pelagophycus porra*, *Alaria fistulosa*, *Nereocystis luetkeana*, and *Macrocystis pyrifera*, named in the reverse order of their present economic importance. Only two of these, the latter two, at present should be considered in a fertilizer connection, as of the former two, the *Pelagophycus porra* occurs in too small quantities to be important, though it carries a very high proportion of valuable fertilizer ingredients, and the *Alaria fistulosa* is too low in potassium to merit treatment where the other kelps are available in sufficient quantities.

The Nereocystis is an annual whose seasonal growth attains an average of 50 feet. The rapid growth necessary to reach such a size in a growing season denotes an abundant supply of the elements or compounds which enter into the plants' metabolism, and this, in turn, indicates a large and constantly changing volume of the medium in which it grows. Thus it is found in localities of heavy surf or strong tideways. To maintain itself in position under these conditions it must attach itself firmly to the bottom. Therefore a rocky bottom is essential to the establishment of groves of the plants. To attach itself, the plant develops a "holdfast," a rootlike growth which tends to grow around and grasp the objects with which it comes in contact, thus anchoring the plant. Extending upward from the holdfast is the stipe, a long, slender stem, cordlike and tough, which reaches almost to the surface of the water. Toward its upper end it gradually enlarges, becoming hollow, and culminates in a hollow bulb. This portion, being air filled, serves to float the plant, and is called the pneumatocyst. The plant thus is lifted and held in the sunlight. From the top of the pneumatocyst develop two tufts or bunches of long, ribbonlike leaves, called fronds, which grow 10 or 15 feet in length and trail out in the tidal currents. The most interesting characteristic of the plant, and a characteristic that distinguishes it from the other important kelp, the Macrocystis, is that almost the entire plant, on the basis of weight, lies on or at the surface, from the enlarged portion of the stipe upward. This fact has an important bearing on the harvesting of this species, as cutting the stipe a few feet below the surface severs practically the entire plant.

The Macrocystis, a perennial, reaches an average length of 100 feet and grows likewise in regions favored by a rocky bottom and a swift tideway or heavy surf. It attaches itself in the same manner as does the Nereocystis—which is characteristic of the kelps—but instead of a single stipe extending from the holdfast it develops a number, which give the effect of a bushy or branching plant. The fronds are distributed along the entire length of the stipe. These reach a maximum of about 3 feet in length and decrease in size as the upper or younger end of the plant is approached. A short section of stem connects the frond to the stipe and bears a pear-shaped enlargement, which is hollow and serves as the pneumatocyst. The plant does not stop growing on reaching the surface, but a large portion of its length lies upon the surface, supported by its numerous pneumatocysts, and trails out in the tidal currents.

Reproduction by these species is by means of sporangia, small bodies which develop on the fronds, in the case of the Macrocystis on the old fronds near the bottom, and which are thrown off to find lodgment and develop into new plants. As the Nereocystis is in effect an annual, its continuance is dependent on annual reseeding. While plants have been observed which have withstood the winter's cold and storms, thus appearing to be at least a biennial, most of the groves are torn out by storms during the winter and re-formed during the following summer. In harvesting these groves, then, due precautions must be taken to leave enough plants for resporing, or to postpone harvesting until after the sporing season. In the case of the Macrocystis it is probable that no such precautions need be observed.

In this connection it should be said further that only one harvesting per season of the Nereocystis is possible, since cutting that plant a few feet below the surface of the water, as pointed out, severs the entire growing portion. It is necessary, then, to await the new growth of the next season.

Such is not the case with the Macrocystis. Cutting that plant a few feet below the surface of the water severs only the upper part of the growing portion, possibly one-half, and does not kill the plant. On the contrary, there seems to be a certain stimulation in growth exhibited by a sort of "stooling" effect: while the old stipes slowly decay, fresh shoots appear, resulting in a thicker growth. It is estimated that after a cutting, a grove resumes its original condition after a lapse of 40 to 60 days.

DISTRIBUTION AND QUANTITIES.

On the Pacific coast of the United States the two commercially important kelps, Nereocystis and Macrocystis, characterize, respectively, the northern and southern stretches of that coast. While it is true that they are found together at certain places and that either one or the other occurs in thin fringes or patches along the entire length of the coast, the Nereocystis occurs in large and thick groves in the Puget Sound region and the Macrocystis on the California coast south of Point Sur. In southeastern Alaska large groves of both species occur; and in western Alaska, in the neighborhood of Kodiak Island and the mouth of Cook Inlet, the Nereocystis is found.

The important groves from the Mexican boundary to the Canadian line on Puget Sound during the past three years have been measured and mapped to scale; likewise, the important groves of southwestern and western Alaska have been surveyed.[1] As a result of the three years' work, it is known pretty definitely what the available quantities of kelp are in the various sections of the coast. Economically, the important groves group themselves around certain centers where there are harbors and where labor and transportation facilities are favorable. The natural centers are Puget Sound, Santa Barbara, San Pedro, and San Diego, on the coast of the United States, and Ketchikan and Kodiak, in Alaska.

The Puget Sound groves, it is estimated, can be made to yield 390,000 tons of wet kelp per year. The principal grove here, in convenient reach of Bellingham or Anacortes, is the Smith Island grove, which, it is calculated, would produce 100,000 tons per season. Other important groves lie near the American shore of the Strait of Juan de Fuca (85,000 tons) and the San Juan Islands.

Opposite Santa Barbara is a grove of approximately 3.9 square nautical miles, which would yield about 320,000 tons of wet kelp per cutting. Near San Pedro, extending from Point Fermin to Malaga Cove, are two groves of a joint area of 2.4 nautical square miles which at a single harvesting should produce 194,000 tons of wet kelp. Near San Diego, north of Point Loma, likewise are two groves of a combined area of 7.7 nautical square miles from which could be harvested at one cutting about 633,000 tons.

In southeastern Alaska 70 square miles of kelp beds have been surveyed, carrying about 8,000,000 tons of wet kelp. These are distributed along a coast line of about 6,000 miles in a region of many

[1] The groves of the Pacific coast of the States were surveyed by Capt. W. C. Crandall, of the La Jolla Marine Biological Institute; those of Puget Sound and Alaska, by Profs. T. C. Frye and G. B. Rigg, of the University of Washington.

islands and circuitous fiords and arms of the sea. While the length of the shore line, relatively speaking, is enormous, the actual distances from point to point are not great. Thus the entire area of this portion of territory is about 25,500 square miles, which is about the area of the States of New Hampshire, Vermont, and Massachusetts.[1] Of the amount of kelp surveyed, groves containing 2,880,000 tons are regarded as easily available, the availability being estimated on the basis of quietness of water and freedom from rocks and other obstructions to navigation.

The kelp of this region has been grouped around eight centers, which are:

1. Port McArthur, near the south end of Kuiu Island.
2. Shakan Bay, on Sumner Strait.
3. Tyee, near Point Gardner.
4. Duke Island, possibly inside the Vegas Islands.
5. Saginaw Bay, at the north end of Kuiu Island.
6. Warren Cove, on Warren Island.
7. Barrier Island, between Cape Chacon and Cape Muzon.
8. Bay of Pillars, on Chatham Strait.

These points have been selected by Prof. Frye from the viewpoint of amounts of available kelp and convenience of harbor.

In this region, as well in western Alaska, large and heavy groves of *Alaria fistulosa* occur. This is a kelp which attains great size, but carries only a small proportion of potash. Its nitrogen content is correspondingly high, but not high enough to make it of equal commercial importance with the other two species.

The kelps of western Alaska so far mapped (by Prof. G. B. Rigg, of the University of Washington, during the summer of 1913) contain about 3,500,000 tons of green kelp, the estimate being based on the supposition that the kelp would be cut about 5 feet beneath the surface. The species included are both Nereocystis and Alaria. "Of this, 1,251,200 tons are in beds of pure Nereocystis; 1,457,300 tons are in beds of mixed Nereocystis and Alaria.[2]

Large kelp beds are within easy reach of the harbors of Port Graham, Seldovia, Kodiak, and Alitak, on Olga Bay.

COMPOSITION.

The composition of the kelps here is considered only from the point of view of their fertilizer value. In the following tables are given the respective composition of a number of samples of Nereocystis

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[1] From the report of Dr. T. C. Frye on the Kelps of Southeastern Alaska, Rept. 100, U. S. Dept. of Agr., Part IV.

[2] G. B. Rigg, report on the Kelps of Western Alaska, ibid., Part V.

and Macrocystis, collected from various localities through a number of years and analyzed in the laboratories of this bureau. These tables are made up of results published elsewhere by the writer,[1] Lindemuth and Parker,[2] and Merz.[3] The samples may be regarded as average samples, since they were collected only as representative of the groves distributed along the coast.

TABLE X.—*Chemical composition of Nereocystis.*

Location.	K_2O.	I.	N.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Fresh Water Bay, Puget Sound	18.04	0.23	2.26	51.13
	17.61	.24	2.21	51.11
	31.62	.25	1.21	33.15
	16.92	.20	2.57	51.16
	17.05	.24	2.71	51.67
	17.32	.28	2.53	50.12
	16.20	.19	2.54	52.14
	16.50	.30	2.21	37.40
	16.72	.20	1.46	39.02
San Juan County, Wash	25.70	.08	1.29	41.80
	13.30	.15	2.52	61.50
	23.00	.17	1.32	46.20
	16.20	.15	2.32	35.30
Point Arena, Cal	16.72	.13	2.22	53.56
	20.62	.15	2.25	51.42
Bay of Monterey, Cal	16.96	.20	2.15	57.25
	23.82	.17	2.41	47.26
	21.70	.18	1.58	50.20
Point Pinos, Cal	19.40	.12	1.70	53.00
	26.10	.15	1.12	40.60
Cayucos, Cal	20.83	.24	1.93	47.86
Geese Island, Alaska	28.26	.06	1.06	43.52
	15.44	.14	2.27	56.26
Port Graham, Alaska	24.69	.06	1.15	40.50
	14.78	None.	2.02	42.74
Pearse Canal, Alaska	12.74	None.	2.87	60.50
	23.88	None.	1.53	39.90
Between Tongass and Kanagunut Islands	15.12	.07	3.06	55.56
	30.12	.05	1.07	33.50
Gulf of Esquibel, Alaska	27.02	None.	.81	39.92
55° 37′ N., 133° 28′ W	19.63	None.	1.04	49.28
Eagle Island, Davidson Inlet, Alaska	16.74	.06	1.52	51.60
Wrangell Straits, Alaska	24.80	.03	.98	42.78
55° 54′ N., 133° 30′ W	28.76	None.	.59	32.66
56° 36′ N., 133° 57′ W	17.67	.01	2.01	50.62
56° 12′ N., 133° 40′ W	20.12	.06	1.85	48.56
56° 08′ N., 133° 54′ W	26.05	.10	1.46	43.78
55° 36′ N., 132° 57′ W	21.61	.09	1.65	43.50
57° 01′ N., 134° 34′ W	22.73	Trace.	1.54	55.56
Average	21.49	.11	1.80	47.75

[1] J. Ind. Eng. Chem., **4**, 9 (1912).
[2] J. Ind. Eng. Chem., **5**, 287 (1913).
[3] J. Ind. Eng. Chem., **6**, 19 (1914).

TABLE XI.—*Chemical composition of Macrocystis.*

Location.	K_2O.	I.	N.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Low Point, Wash.	12.80	0.23	1.37	59.40
Neah Bay, Wash.	19.60	.20	1.81	51.50
Pillar Point, Cal.	17.26	.15	2.18	58.14
	27.66	.14	1.00	41.04
Santa Cruz, Cal.	16.44	.24	2.16	59.80
Monterey Bay, Cal.	18.30	.26	2.32	57.00
	12.38	.18	2.11	68.80
Point Aulon, Cal.	23.00	.32	1.83	51.20
Point San Luis, Cal.	8.62	.14	2.35	68.26
Rocky Point, Cal.	9.35	.25	2.72	73.06
Point Conception, Cal.	14.17	.24	2.15	62.95
San Miguel Island.	16.40	.29	1.54	50.60
Santa Cruz Island.	17.40	.32	1.57	49.40
Anacapa Island.	12.60	.26	.95	64.40
Cape Quemada, Cal.	14.10	.29	.90	63.50
Goleta Point, Cal.	16.70	.17	1.00	56.70
Point Las Pitos, Cal.	12.30	.20	.98	66.20
La Jolla Point, Cal.	13.60	.38	1.04	64.40
Point Medanos, Cal.	13.40	.23	.74	62.90
Point Loma, Cal.	15.70	.15	.90	60.90
Between Duke Island and Bee Rocks, Alaska.	11.49	.06	1.08	67.34
56° 21′ N., 133° 36′ W.	8.63	None.	2.68	72.24
57° 13′ N., 133° 34′ W.	6.92	Trace.	2.69	73.96
57° 01′ N., 134° 34′ W.	7.30	None.	2.19	73.24
55° 22′ N., 133° 16′ W.	13.26	.10	1.25	64.36
54° 58′ N., 132° 29′ W.	22.48	.30	2.64	49.02
Average.	13.63	.19	1.83	63.00

In these tables the potash is recorded as such—that is, as the oxide, the conventional manner of expressing the potassium content of fertilizers. It must not be understood that this is the form in which it occurs in the plant. When the plant has been incinerated at low heat, so that all volatile organic matter has been driven off and only charcoal remains, and leached, potassium chloride is obtained. While it is not known definitely what compound of potassium exists in the living plant, it may be regarded as potassium chloride. In addition to the potassium chloride, sodium chloride is present in varying amounts, roughly equal to about one-third that of the potassium chloride. Also, there are small quantities of phosphoric and sulphuric acids, calcium, and magnesium. By lixiviation practically all of the soluble salts, principally of potassium and sodium, are removed. If the remaining charcoal then be burned, an ash remains which consists essentially of calcium and magnesium carbonate and phosphate. The percentage of ash varies from 3 to 12 per cent, the variations being determined by the part of the plant undergoing analysis. The stipe carries a much higher proportion of ash than the leaves or fronds.[1]

[1] For analyses of the various kelps of the Pacific coast other than and including those of commercial importance, and for others of various algæ of various parts of the world copied from the literature, see App. P of S. Doc. 190, Sixty-second Congress, second session.

From the results of analyses recorded above the following generalizations have been made:

(1) No definite quantitative relations exist between the different constituents of kelp.

(2) The potassium content of Nereocystis is greater than that of Macrocystis.

(3) The potassium content of northern kelp is higher than that of southern kelp.

(4) There is no positive difference in iodine content between northern and southern kelps.

The following conclusions also seem justified:

(5) The proximity of the mouth of a fresh-water stream has no appreciable effect on the potash and nitrogen content of kelp.

(6) There are no essential differences between the potash and nitrogen content of fronds and stipes.[1]

KELP AS A FERTILIZER.

In the British Isles kelp has been used as a fertilizer for centuries. So highly was it valued that lands carrying kelp-harvesting privileges were especially valuable. In New England, also, kelp or seaweed has found favorable use as a soil amendment. In Alaska, especially on Kodiak Island, near the village of Kodiak, and in the neighborhood of Skagway, it is used in like manner, on the former island particularly in fertilizing potatoes and in the latter region on truck gardens.

The Pacific kelps are markedly different from the seaweeds of the Atlantic coast, especially in their very much greater size and their relatively large content of potassium chloride. It is these two qualities that give them especial importance as a possible source of fertilizer materials.

In the regions mentioned kelp has been applied to the soil as a mulch in its green state, or, better, after it has been cured by drying in the sun, or rotted by being allowed to stand in heaps.

For several years past kelp has been harvested mechanically near San Pedro, Cal., and shipped in the crude, undried condition to the ranches and orchards of that part of the State. As the green kelp, after draining, contains about 85 per cent water, its content of potash and nitrogen are about 2.6 per cent and 0.3 per cent, respectively. These values are obtained by calculating back from the values established on the dry basis to that of a content of 85 per cent water.

The manurial value of green kelp, as compared with a number of other materials commonly used as fertilizers, is brought out in the following table:[2]

[1] Cameron, Kelp and Other Sources of Potash, J. Frank. Inst., October, 1913, p. 363.

[2] Cameron, loc. cit., p. 377.

TABLE XII.—*Comparison of the composition of wet kelp with other manurial products.*

Material.	Moisture.	Nitrogen.	Potash.	Phosphoric acid.
Horse manure:[1]	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Solid fresh excrement		0.44	0.35	0.17
Fresh urine		1.55	1.50	
Stable manure[1]	73.27	.50	.60	.30
Green alfalfa[1]	75.30	.72	.45	.15
Cowpeas[1]	78.81	.27	.31	.98
Street sweepings, Washington, D. C.[2]		.86	.55	.55
Wet kelp	85.00	.30	2.50	.10

[1] From Soils, by S. W. Fletcher.
[2] From Analyses, by J. G. Smith, Bureau of Soils.

The high content in water of the green kelp and its resulting low content in valuable constituents restricts its use to regions within easy reach of the points where it is harvested. For that reason any scheme for the large-scale utilization of kelp as a fertilizer must be based on some method of concentrating its valuable constituents. Since all of these are either neutral or beneficial from a fertilizer point of view, it is necessary only to concentrate them by the removal of the water, or in other words by drying. After an investigation of several years and a careful consideration of the nature of the raw materials involved, the value of the products obtainable and the costs of obtaining them, together with the demands of the fertilizer trade and the economic conditions existing on the Pacific coast, it appears that kelp, in the beginning at least, most advantageously can be prepared for the fertilizer trade merely by drying and grinding.

The product obtainable, as shown by small-scale operations, is a coarse gray powder of such specific gravity that a cubic foot weighs 51 pounds. While it does not absorb moisture readily from the air, when wetted it swells and may become sticky and gelatinous.

In composition it would approximate closely the values obtained from the foregoing Tables X and XI. The drying would not be quantitative; that is, a certain proportion of water would be allowed to remain, probably 7 to 10 per cent. Assuming the larger figure, the other values would be reduced proportionately, namely, 10 per cent. The pulverized kelp, then, would contain 15.8 per cent potash and 1.6 per cent nitrogen. On the retail market of the Pacific Coast States, the prices of $1 per unit of potash and $3.30 per unit of ammonia are obtainable. On this basis the value of the kelp per ton is arrived at, as follows:

15.75 per cent K_2O at $1	$15.75
2.18 per cent NH_3 at $3.30	7.19
Total value per ton	22.94

In the wholesale market of the East, the prices obtainable are $0.65 per unit of potash and $2.85 per unit of ammonia, on the basis of which the value of the kelp would be:

15.75 per cent K_2O at $0.65	$10.24
2.18 per cent NH_3 at $2.85	6.21
Total value per ton	16.45

From the analyses of the dry kelp it is seen that it is distinctly a potassic fertilizer, and would enter the trade as a potash carrier. Since the present practice is to use the mixed or "complete" fertilizers, the kelp, if produced on a large scale, would find its market as a potash carrier to be mixed with phosphates and ammoniates to form the "complete" fertilizer. For this purpose, it would enter into competition with other potash carriers, including the German potash salts. These are, principally, kainite, a double salt of potassium and magnesium, $MgSO_4KCl3H_2O$, and "manure salts," a mixture of potassium, sodium, calcium, and magnesium salts. Kainite, when pure, has a theoretical content of 18.9 per cent potash, but in the impure condition in which it is found on the market carries about 12.5 per cent potash. It sells for about $8.25 per ton. "Manure salts" vary widely in their potash content, but generally are of low grade and carry about 12 to 18 per cent potash. At present kainite, as such, is disappearing from the market, being classified with "manure salts."

A comparison of the efficiency as a fertilizer of the potash in kelp and that in potassium salts, of the general type used in mixed fertilizers, has been made in the laboratories of this bureau by Skinner and Jackson.[1] The two were applied to growing plants in equivalent amounts. The results showed that the kelp as a potassic fertilizer was quite as effective as the potash salts.

Since sodium chloride is found as a constituent of kelp, it has been suggested that its use on alkaline soils might prove objectionable. In reply to this it should be said that the amount of salt actually added to the soil in the kelp is extremely small, and in such amounts it has been shown to exhibit fertilizing properties. Further, sodium chloride makes up but a small proportion of alkali, that being either sulphate of calcium or magnesium or carbonate of soda. If such an objection were valid, it would apply much more to the materials now in use as potash carriers, the "manure salts," which have been seen to contain soluble salts of both calcium and magnesium. In the case of the potash salts, the constituents other than potash have no value on a fertilizer basis and therefore are merely so much inert material on which transportation must be paid. The deleterious action of these in some soils would be un-

[1] Circ. 76, Bureau of Soils, U. S. Dept. of Agr.

doubted if the fertilizers of which they form a part were used in very great amount. They are objectionable on the further score that they render the material of which they form a part hygroscopic, which property in moist air causes the fertilizer to cake. The ingredients of kelp other than potassic, it has been shown, are salt and organic matter, the nitrogen of which, rated as ammonia, adds materially to the market price of the product. The organic matter itself is of value, as contributing—to a small extent, to be sure—to the organic constituents of the soil, known by the indefinite term of "humus."

PREPARATION OF DRY FERTILIZER FROM KELP.

Since the ingredients of kelp are either neutral or beneficial in their influence on plant growth, to prepare kelp for use as a fertilizer it is necessary only to convert it into a form in which it can be preserved and shipped. To accomplish this it is sufficient to harvest, drive off the water which it contains, and grind it to a coarse powder for bagging and mixing.

Kelp is being harvested by a machine which embodies the principles of the mowing machine or reaper used in harvesting agricultural products. The harvester actually in operation consists essentially of a barge over the end of which projects an adjustable frame, supporting an endless belt, tilted to form an inclined plane. Across the lower end of the belt extends a horizontal cutting bar about 10 feet in length, of the type used in the construction of reapers, which is supplemented at each end by two perpendicular knives. By this arrangement a swath may be cut through the kelp 10 feet in width and of a depth determined by the adjustment of the supporting frame. Back of the knives the belt, constructed of chains and netting, is operated in such a way as to catch the severed kelp and lift it upon the barge. Beneath the upper end of the belt is a chopper into which the kelp drops and by which it is cut into short lengths. From this it passes onto a short conveyor which loads it into a large scow made fast alongside. The small barge carrying the cutter is moved along the side of the large scow so that the load of cut kelp is distributed evenly. To operate the moving parts of the machine a gasoline engine is provided. The barge and scow are pushed through the kelp groves by a launch, which serves also to tow them to the dock for unloading. (Pl. VI, fig. 2.)

The cost of cutting will be determined by the conditions obtaining at the place of cutting. The results obtained so far indicate that this will be not more than 50 cents per raw ton, and easily may be reduced to 25 cents or less, inclusive of unloading at the dock.

It can not be expected that the cutter now in operation embodies all the perfections to which such a machine is susceptible, nor that improvements in the machine will not reduce the cost of cutting. Certain features of the present method of operation are objectionable. But these almost certainly will disappear when a fuller experience shall have pointed them out and the means of circumventing them. Cutters of other forms and modifications of the present cutter have been designed and patented. Conspicuous among these are machines ascribed to S. A. Knapp (U. S. Patent No. 756,658) and George H. Ennis (U. S. Patent No. 1,080,144). In spite of its imperfections, the kelp cutter now in operation must be regarded as an unqualified solution of the problem of the economical harvesting of kelp.

The chopped kelp may be unloaded at the dock by an elevator such as that recommended for unloading cannery waste. In fact, the identical elevator may be employed in the same manner as in unloading the other class of material.

The drying of such materials as fish pomace, a class in which kelp likewise may be included, has been discussed in foregoing paragraphs. It should suffice to say here that from a priori considerations, as well as the results gotten so far in actual experimentation with kelp in the large-sized, hot-air drier and on a semicommercial scale, this type of drier seems entirely adapted to the drying of kelp.

Since, under Atlantic coast conditions, fish pomace containing 55 to 60 per cent water may be dried in the direct-heat rotary drier at a cost of about 50 cents per dry ton, it seems reasonable to believe that it should be possible to dry kelp, containing 85 to 90 per cent water, at a cost of $1 per dry ton. After drying it may be found desirable to grind the kelp for mixing. Dry kelp, especially when hot, is quite brittle and grinds easily.

Frye, in his work on Alaskan kelps, has shown that the leaves of Nereocystis yield 9.2 per cent solids and the stems 7.2 per cent, and that the Macrocystis, stems and leaves together, yields 13.27 per cent solids. *Alaria fistulosa* produces 13.74 per cent solids. These results were obtained by weighing specimens immediately on being taken from the water while they were still wet with sea water. On the basis of these values and the analyses given in the foregoing tables the following calculations have been made, showing the yield in various constituents to be expected from a definite weight of freshly cut kelp:

TABLE XIII.—*Yield in various constituents to be expected from 1,000 tons of freshly cut Macrocystis and Alaria.*

Variety of kelp.	Wet kelp.	Dry kelp.	K_2O.	N.
	Tons.	*Tons.*	*Tons.*	*Tons.*
Macrocystis	1,000	132	25.3	2.2
Alaria	1,000	137	13.3	3.6

TABLE XIV.—*Yield to be expected from 1,000 tons of Nereocystis.*

Material.	Leaf.	Stem.	Total.	Remarks.
	Tons.	*Tons.*	*Tons.*	
Wet kelp	775	225	1,000	Counting 3½ times as much leaf as stem.
Dry kelp	71	16	86	Leaves average 9.2 per cent dry; stems, 7.2 per cent.
K_2O	12	4	16	Leaves, 17.05 per cent K_2O; stems, 26.45 per cent K_2O.
N	1.54	.17	1.7	Leaves, 2.16 per cent N; stems, 1.09 per cent N.

A COMBINED FISH SCRAP AND KELP FERTILIZER PLANT.

One of the objections to the idea of a central rendering station for the treatment of cannery waste is the great length of time when the plant and its equipment lies idle. To overcome in part this objection it has been proposed that the fish-rendering plant, at times when fish waste is not available, be applied to the preparation of kelp fertilizer. More accurately, the suggestion is that the rendering of fish waste be resorted to as an operation auxiliary to the treatment of kelp. But as the rendering of fish waste requires more specialized apparatus than the drying of kelp, it appears more plausible to regard the treatment of kelp as subsidiary to the former.

With a plant fully equipped for the large-scale rendering of fish waste, all the equipment necessary for treating kelp, with the exception of a kelp harvester, has been supplied. Scows and tugs designed for the collection of cannery waste can be applied to the harvesting of kelp. The unloading elevators, storage bins, and conveyors within the plant are entirely adaptable to chopped kelp. Since the kelp is not to be cooked or pressed, the conveyors should be arranged with a view to the transference of the material directly from storage bin to drier. And the drier, of whatever form, probably would be found quite suitable for drying kelp.

Assuming the canning season, for example, in the Puget Sound region to be confined to the months of July and August, the equipment of the rendering station can be applied to the treatment of kelp during the months of September, October, and probably November, thus more than doubling the activity of the plant. The capacity of the drier, for the plant proposed in the foregoing paragraphs, in actual practice is about 50 tons per day, which is equivalent to about 500 tons of wet kelp. Furthermore, even during the canning season, when the amount of fish waste available is not sufficient to keep the plant running at full capacity, kelp may be harvested and dried as a supplementary operation.

The following estimates may serve to convey some idea of the cost and profits to be expected from the supplementary operations on kelp. Since the drier has a capacity of 50 tons of dry kelp, the capacity of the plant is limited to the equivalent weight of green kelp, which, on the basis of 10 per cent solids in the green, is 500

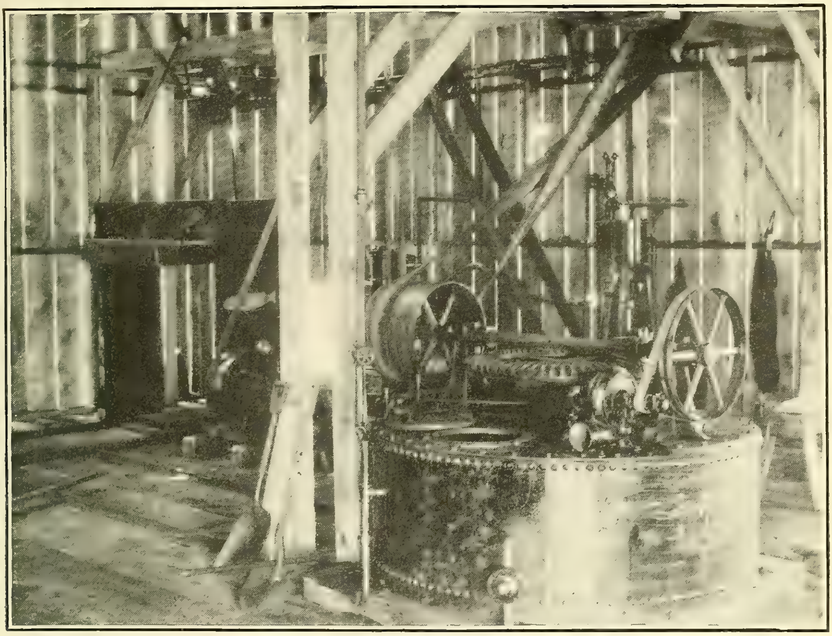

FIG. 1.—SMALL STEAM DRIER USED IN SALMON-CANNERY BY-PRODUCTS PLANT.

In the background the press is seen.

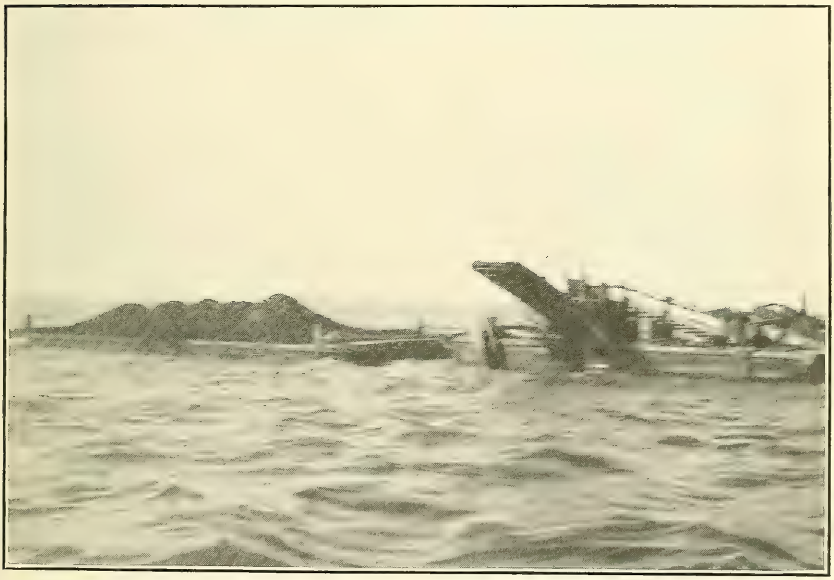

FIG. 2.—A KELP HARVESTER AND BARGE LOADED WITH HARVESTED AND CHOPPED KELP.

tons. This, it is assumed, could be harvested and unloaded at 50 cents per ton. Such an amount of material probably would require at least two cutters and five barges of 100 tons capacity each; and to tow these to the factory dock, two tugs would be necessary.

During the season when cannery waste is being collected, the labor required would be on wages, whether actually employed or not. Under such circumstances the labor cost need not be considered, but only the actual expense of operating the tugs and cutters. After the close of the cannery season, however, the cost of labor would have to be borne by the kelp. Any estimate of this cost would be difficult and perhaps misleading, but it scarcely would be under $50 per day. About one-half of this estimated cost of labor would be included in the cost of harvesting, and the balance in the cost of drying and sacking. The drying, it is estimated, would cost $1 per dry ton. To sack the product $2 per dry ton is a fair estimate, as a sack would hold over 100 pounds; the bags would cost something less than 10 cents each, including string.

The principal expenses of operation may be itemized as follows:

Harvesting, 500 tons, at 50 cents	$250.00
Drying, 50 tons (dry), at $1	50.00
Bagging, 50 tons, at $2	100.00
Overhead charges, selling, and depreciation, 50 tons, at $1	50.00
Total	450.00
Freight to eastern centers, at $6	300.00
	750.00

The proceeds from the sale of the product may be estimated as follows:

On basis of retail sales, 50 tons, at $22.94	$1,147.00
On basis of wholesale sales, 50 tons, at $16.45	822.50

An estimate of daily profits may be made as follows:

Retail basis:	
Daily proceeds	$1,147.00
Daily expenditures	750.00
Daily profits	397.00
Profits for 30 days' operation	11,910.00
Wholesale basis:	
Daily proceeds	822.50
Daily expenditures	750.00
Daily profits	72.50
Profit for 30 days' operation	2,175.00

While very great accuracy can not be claimed for these estimates, as they are based on experience with materials other than kelp, it is believed that they are approximately correct and can be taken as an indication of what the items of expenditures and proceeds may be. They indicate strongly that a plant erected and equipped for rendering cannery waste can be applied with profit to the treatment of kelp. The proviso that the plant be equipped with a drier of large capacity must be introduced. In the beginning of the proposed industry the market on the Pacific coast would consume the entire product, so that the high freight rates to the Atlantic seaboard could be avoided. This would add materially to the profits.

The products of the proposed combined fish-rendering and kelp-drying plant may be disposed of separately to mixers of fertilizers, or they may be mixed and retailed directly to the consumers as so-called complete fertilizers. The mixture of fish scrap and dried kelp would contain ammonia, potash, and phosphoric acid (bone phosphate), the three substances regarded as essential ingredients of a complete fertilizer. Mixed in equal proportions, the analysis of the product would approximate 5 per cent nitrogen, 3.5 per cent phosphoric acid, and 7 per cent potash. Such a fertilizer, from the conventional point of view, would be regarded as deficient in phosphoric acid, that ingredient being added usually in larger proportion than the potash or nitrogen. To make it conform to that formula, acidulated phosphate rock could be added. However, this ratio is purely conventional and may be disregarded.

FISH SCRAP FROM OTHER FISH.

It has been shown that at present about 1,630 tons of dried fish scrap represents the annual output of that product from the refuse from the salmon industries. In addition thereto, small quantities of scrap are produced from the herring, tuna, and whale fisheries, and a considerable waste is discarded in the halibut fisheries.

HERRING.

At Killisnoo, Alaska, is the only fertilizer plant on the coast using herring as its raw material. The company operating the plant was organized in 1889. In 1909 the plant was equipped with new and improved apparatus. The methods in vogue are the same as those employed in the menhaden industry on the Atlantic coast.

The Killisnoo plant uses about 40,000 barrels of 200 pounds each of raw herring per year, from which about 1,000 tons of dry scrap and 3,500 barrels of oil are yielded.

The herring utilized are obtained in the waters of and adjacent to southeastern Alaska. In the same region there has been developed a small herring fishery which salts herring for the market. This industry, presumably, is only in its infancy. However, at present the Alaska herring are not in demand, bring a low price, and exhibit poor keeping properties.

During the year 1913 about 6,000,000 pounds of herring were prepared for use other than in the manufacture of fertilizer. This application of herring is itemized in the following table:[1]

TABLE XV.—*Use of herring other than for fertilizer.*

Application.	Quantity.	Value.
	Pounds.	*Dollars.*
Fresh, for bait	3,936,500	22,245
Frozen, for bait	231,935	2,291
Pickled, for food	692,400	26,832
Pickled, for bait	256,200	3,297
Dry salted, for food	5,259,520	50,183
Smoked, for food	17,371	1,257
Total	10,393,926	106,105

Even in the present stage of development of the herring-salting and herring-fertilizer industries, the two are supposed to be in conflict with each other, and it is being proposed that the fertilizer industry be suppressed. Since the food demands of the Nation must take precedence over all others, if the manufacture of fertilizer from herring is bringing about such a depletion of the supply of these fish that the demands for them as a food fish are not satisfied, it is fitting that the former use be restricted or suppressed. There seems to be no authentic information substantiating the belief entertained by some that the herring-salting industry is suffering from the activity of the herring-fertilizer industry. In fact, when the herring fisheries of Alaska are compared with those of the northern shores of the Atlantic, it is seen that the total number caught there is insignificant; about 22,000,000 pounds are utilized in Alaska for all purposes, while in the north Atlantic, about 900,000,000 pounds are utilized.

Obviously, it is greatly to the advantage of the Nation that the fish of the sea be put to some use. Their application to the soil as fertilizer is only one step removed from their direct utilization as food, since when so used they go to increase the food supply. Their utilization in this manner is very much more to the advantage of everyone concerned than putting them to no use whatever. Ultimately, the fish resources of the country will be developed to their fullest economical usefulness, when they will be drawn upon to supply man with greatly increased amounts of food. Until such a time they should be open to supervised use in whatever way industry demands.

[1] From Bower and Fassett, loc. cit.

In this connection the opinion of the experts of the United States Bureau of Fisheries is of interest:

> The concensus of opinion is that herring have been more numerous this season in the water of Alaska, except in the Yes Bay section, than for a number of years past. At no time heretofore has there been anything like an alarming shortage, but as in the case of herring fishery the world over, there are periodical lean and full years. It not infrequently happens that during the poorer years alarmists give rise to the view that the supply of herring is being diminished through ruthless fishing operations. Particularly has this idea been directed toward the practice of utilizing herring in the manufacture of fertilizer and oil. That this opinion is not borne out in fact has been clearly established by careful and impartial analysis of the situation. So far as Alaska is concerned, the destruction of countless millions of herring in embryo by the natives, who use large quantities of impregnated eggs for food purposes, is a more destructive agency than the use of the adult fish for fertilizer purposes. Measures should be adopted to prohibit the natives from placing brush on the spawning grounds by means of which they remove the eggs.
>
> The halibut fishermen are particularly interested in the herring situation, because of the dependence of their industry upon the supply of herring for bait. Much of the agitation as to the fertilizer and oil question has emanated from this source. Unless future developments show radically different conditions, as compared with other parts of the world where time has been the infallible test, there will be not only enough herring in Alaska waters to meet present-day needs, both for bait and fertilizer, but to permit of an expansion along these lines, as well as a growth of the food-herring industry.[1]

In the face of the present successful opposition, however, it seems scarcely reasonable to believe that there will be any further development in the manufacture of fertilizer from herring.

During the season of 1913 Alaska herring yielded 1,200 tons dried fertilizer and 260,000 gallons of oil. For this purpose 57,800 barrels of 200 pounds each of raw herring were rendered.

TUNA.

The canning of California tuna, or more properly, the Albicore, is a development of only recent years. At present it is carried on by about nine canneries in southern California, the center of the industry being San Pedro. The output for the year 1913 amounts to about 115,000 cases.

The waste from the tuna is very large. The fish are dressed, as caught, at sea and the waste thus produced is thrown overboard. This represents about 20 per cent of the fish. After delivery at the cannery it is cooked, when its weight decreases about 18 per cent, due to loss in the removal of oil and soluble constituents. After cooking, the bones, skin, and dark-colored flesh are removed, representing a further loss of about 32 per cent. The total loss from the round weight of the fish to the finished product is about 70 per cent.

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[1] From Bower and Fassett, loc. cit.

Present practice makes the greater part of this available for the manufacture of fertilizer. Since the material is cooked before discarding, some of the oil has been released, thus detracting from the value of the material as a source of oil. What proportion of oil thus is lost can not be said. It is probable that only a little more cooking is necessary to render the material suitable for pressing.

At present a considerable part of the cooked meats (about 500 tons per year) is disposed of for the manufacture of fertilizer. To effect this the waste is only dried in a steam drier, no attempt being made to recover the oil present. During the season of 1913 about 50 tons of tuna fertilizer were prepared. A sample of this was analyzed by J. R. Lindemuth, the results of which are given in Table XVI.

The tuna-canning industry shows promise of development. The fine qualities of the product have brought it into demand. The present pack represents an initial or round weight of 16,400,000 pounds. If all the waste from this (70 per cent) were saved, it would yield about 5,700 tons, or if only that produced at the canneries were saved it would amount to about 4,000 tons of undried scrap.

HALIBUT.

Halibut are caught by hook and line, trawl, or "ground line." At the end of each day's fishing the catch is partially dressed, the viscera being removed, and is packed in ice for transportation to the halibut stations for the final preparation for market. The waste produced in the preliminary dressing is thrown overboard. At the halibut stations, generally fish-freezing stations, the heads are severed and the fish are subjected to a final cleansing before being frozen for storage or shipment. The heads represent about 14 per cent of the weight of the fish as delivered at the stations. The present practice is to throw these into the water at the stations, at the end of the day's work, in the manner most convenient. As the greater portion of the halibut caught are marketed fresh or frozen, they are shipped whole without further cutting, with the result that the only waste from them produced at the stations is the heads.

During the past season (1913) the Alaska halibut fisheries produced 13,437,800 pounds of halibut. This is the weight of the prepared fish. In producing this weight, about 1,100 tons of heads were discarded, and probably an equal weight of viscera. To preserve the latter and make it available for rendering the oil and preparing the residue for fertilizer, the fishing boats would have to be equipped with ice-cooled tanks for receiving the viscera. This would be objected to on the part of the operators, as frequently all available space on the fishing steamers is taxed to its utmost to accommodate the fish of far greater value than the viscera. It is doubtful, therefore, whether any economical method of preserving this waste could be devised. The heads, on the other hand, easily could be saved, provided the halibut stations were within a convenient distance of a rendering station. At best these could be regarded only as a small auxiliary supply of raw material, for in no instance, probably, is there a sufficient quantity of heads produced at any one station to warrant the installation there of a by-products plant.

The fish taken incidentally in the halibut fisheries constitute another large waste. Concerning this, Messrs. Bower and Fassett, of the United States Bureau of Fisheries say:

> Halibut are almost exclusively caught on trawl or ground lines, which, equipped with hundreds of hooks, are set out from dories in great lengths over the bottom. At intervals, as the weather permits, the lines are underrun, the catch removed, hooks rebaited, and the lines reset, this work also being done from dories. After careful inquiry among halibut fishermen themselves, it is believed to be a safe estimate that for every halibut caught at least one other fish of more or less value as food is taken from the hooks. With those rare exceptions when black cod are retained, all these fish are thrown back into the sea, either dead or soon to perish. Except in so far as they may become food for other species, they may be regarded as a total economic loss.[1]

There is little information on which to base an estimate of the weight of the other fish taken with the halibut. Assuming that this is only 25 per cent of the round weight of the halibut, about 16,000,000 pounds, it would amount to 2,000 tons waste fish. To conserve this for rendering it would be necessary to equip the steamers with storage tanks, which, it has been pointed out, would be regarded as highly objectionable, owing to lack of space. At the present low price which such material brings in the market and the short time in which rendering plants would be in operation, it seems quite improbable that the waste produced in the halibut fisheries will come to play an important rôle as a source of raw materials for the manufacture of fertilizer and oil.

WHALE.

Whaling from shore stations has been reduced to the extent that only two such stations were operated on the Pacific coast territory of the United States during the 1913 season. These were the stations at Port Armstrong, Alaska, and Bay City, Wash. At the former station 186 whales were taken,[2] which yielded 665 tons of fertilizer. At the latter plant about 500 tons of fertilizer and bone meal were prepared. The composition of these products is shown in Table XVI.

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[1] Pacific Fisherman, 12, No. 1 (special), 1914 cf., p. 63.

[2] Bower and Fassett, loc. cit.

Since the whaling industry has undergone a large decline through the depletion of the number of whales, there is little probability that the future will see any marked increase in the production of fertilizer from whale carcasses.

In the following table are reported results of analysis of material prepared from the waste from the sardine, tuna, and whale industries and from dog fish:

TABLE XVI.—*Analysis of dried fish scrap from fish other than salmon.*

[J. R. Lindemuth, analyst.]

Type of fish.	Location.	Nitrogen.	Phosphoric acid (P_2O_5).	Moisture.	Oils.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Sardine	Monterey Packing Co., Monterey, Cal	7.97	7.11	5.57	8.42
Whale meal	Canadian North Pacific Fisheries (Ltd.), Victoria, British Columbia.	11.59	.94	5.41	12.70
Whale bone meal	do	3.01	26.08	2.53	Trace.
Tuna	San Pedro Fertilizer Co., San Pedro, Cal	8.54	7.25	4.21	13.27
Dogfish	Pacific Products Co., Port Townsend, Wash.	12.15	3.59	6.35	7.89

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