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CONTENTS.

DEPARTMENT BULLETIN No. 426.—SUGAR PINE. Page.

Importance of sugar pine ... 1
Geographical and commercial range ... 2
Habit and root system ... 3
Bark, leaves, flowers, and seed ... 3
Size and longevity ... 4
Susceptibility to injury and diseases ... 4
Silvical requirements ... 7
Reproduction ... 8
Forest types ... 9
The wood ... 10
Logging ... 12
Milling ... 13
Values and grades of lumber ... 16
Markets ... 20
Uses ... 20
Stumpage prices ... 23
Growth and yield ... 24
Management ... 30
Management of private timberlands ... 35

DEPARTMENT BULLETIN No. 427.—THE POTATO TUBER MOTH.

Historical ... 1
Distribution ... 2
Possible origin ... 3
Nature of injury ... 4
Economic importance ... 6
Classification and synonymy ... 9
Description ... 9
Food plants ... 14
Life history and habits ... 15
Natural enemies and checks ... 32
Artificial control ... 48
Summary ... 51

DEPARTMENT BULLETIN No. 428.—MEDICAGO FALCATA, A YELLOW-FLOWERED ALFALFA.

Introduction of medicago falcata into the United States ... 2
Natural distribution ... 5
Climatic and soil requirements ... 7
Botanical history ... 8
Botanical description and relationship ... 13
Agricultural history ... 33
Agronomic characteristics ... 35
Cultural investigations ... 51
Possibilities in selection and hybridization ... 56
Present agronomic status ... 61
Summary ... 63

DEPARTMENT BULLETIN No. 429.—LIFE HISTORY OF THE CODLING MOTH IN THE PECOS VALLEY, N. MEX.

Definition of terms used ... 2
Seasonal-history studies of 1912 ... 3
Seasonal-history studies of 1913 ... 34
Summary ... 87

DEPARTMENT BULLETIN NO. 430.—CEREAL EXPERIMENTS ON THE CHEYENNE EXPERIMENT FARM, ARCHER, WYO. Page.

Description of the district ... 2
Cheyenne experiment farm ... 8
Experiments with wheat ... 12
Experiments with emmer and spelt ... 25
Experiments with oats ... 26
Experiments with barley ... 30
Experiments with flax ... 33
Experiments with minor grain crops ... 36
Summary ... 38

DEPARTMENT BULLETIN NO. 431.—SACBROOD.

Historical account ... 2
Name of the disease ... 4
Appearance of healthy brood at the age at which it dies of sacbrood ... 6
Symptoms of sacbrood ... 10
Cause of sacbrood ... 24
Weakening effect of sacbrood upon a colony ... 30
Amount of virus required to produce the disease, and the rapidity of its increase ... 31
Methods used in making experimental inoculations ... 32
Means for the destruction of the virus of sacbrood ... 34
Heating required to destroy sacbrood virus when suspended in water 34
Heating required to destroy sacbrood virus when suspended in glycerin ... 35
Heating required to destroy sacbrood virus when suspended in honey ... 36
Resistance of sacbrood virus to drying at room temperature ... 37
Resistance of sacbrood virus to direct sunlight when dry ... 38
Resistance of sacbrood virus to direct sunlight when suspended in water ... 39
Resistance of sacbrood virus to direct sunlight when suspended in honey ... 40
Length of time that sacbrood virus remains virulent in honey ... 40
Resistance of sacbrood virus to the presence of fermentative processes 41
Resistance of sacbrood virus to fermentation in diluted honey at outdoor temperature ... 42
Resistance of sacbrood virus to the presence of putrefactive processes ... 43
Resistance of sacbrood virus to carbolic acid ... 44
Modes of transmission of sacbrood ... 46
Diagnosis of sacbrood ... 48
Prognosis ... 49
Relation of these studies to the treatment of sacbrood ... 50
Summary and conclusions ... 52

DEPARTMENT BULLETIN NO. 432.—THE SPIKE-HORNED LEAF-MINER, AN ENEMY OF GRAINS AND GRASSES.

Synonymy ... 2
History of the species ... 2
Food plants ... 3
Description ... 5
Distribution ... 7
Injury to plants by adults puncturing the leaves ... 7
Injury to plants by mining habits of larvæ ... 8
Life history ... 9
Rearing methods ... 14
Parasitic enemies ... 15
Preventive measures ... 16

DEPARTMENT BULLETIN No. 433.—CHANGES IN FRESH BEEF DURING COLD STORAGE ABOVE FREEZING. Page.
Hygienic value of cold storage 1
Commercial practices in the cold storage of fresh beef 2
Previous investigations on cold storage of meats 5
Purpose and plan of present investigation 7
Autolysis experiments 8
Cold-storage experiments with fresh beef 29
Effects of cold storage upon the nutritive value of the beef 95
Factors affecting the time that fresh beef can be stored at temperatures above freezing 97
General summary 99

DEPARTMENT BULLETIN No. 434.—JUDGING THE DAIRY COW AS A SUBJECT OF INSTRUCTION IN SECONDARY SCHOOLS.
Classroom discussion 1
Practice judging 16

DEPARTMENT BULLETIN No. 435.—THE APPLE LEAF-SEWER.
History 2
Distribution 2
Feeding habits and character of injury 2
Description of stages 4
Spring pupation of wintering larvæ 6
Emergence of moths 7
Oviposition of moths 8
Length of life of moths 8
Habits of moths 9
Incubation of eggs 9
Larval feeding period 10
Hibernation 10
Natural enemies 11
Remedial measures 11
Summary 12

DEPARTMENT BULLETIN No. 436.—THE DESERT CORN FLEA-BEETLE.
Introduction 1
Distribution 2
Economic considerations 2
Food plants 4
Descriptions 5
Life history and habits 7
Seasonal history 15
Natural enemies 16
Remedial and preventive measures 18
Summary 21

DEPARTMENT BULLETIN No. 437.—FLAT-HEADED BORERS AFFECTING FOREST TREES IN THE UNITED STATES.
Importance of flat-headed borers 1
Food plants 2
Character of the work 2
Life history 2
Seasonal history 2
Special habits 3
Special structural characters 3
Agreement of adult and larval classifications 4
Distinguishing characters 4
Key to genera of buprestid larvæ 5
List of genera, distribution, common habits, and host trees 6
References to important literature 8

DEPARTMENT BULLETIN No. 438.—THE PEAR LEAF-WORM.	Page.
Introduction	1
History and distribution	1
Possible origin	2
Character and extent of injury	3
Description and habits	4
Biology	9
Natural control	17
Remedial measures	18
Summary	22
DEPARTMENT BULLETIN No. 439.—THE SOY BEAN, WITH SPECIAL REFERENCE TO ITS UTILIZATION FOR OIL, CAKE, AND OTHER PRODUCTS.	
Soy beans in Manchuria	2
Soy beans in Japan	4
Soy beans in Europe	6
Soy beans in the United States	7
Methods of oil extraction	9
Soy-bean meal as human food	11
Soy-bean meal as stock feed	13
Soy-bean meal as a fertilizer	14
Uses of soy-bean oil	15
Analyses of important varieties of soy beans	16
Possibility of developing a manufacturing industry with American-grown soy beans	17
DEPARTMENT BULLETIN No. 440.—LUMBERING IN THE SUGAR AND YELLOW PINE REGION OF CALIFORNIA.	
Part I. Introduction	1
The region	1
The forest	2
Types of operations	4
Labor	5
Camps	8
Factors affecting the cut	10
Part II. Logging	13
Preparing logs for transport	13
From stump to yard	18
From yard to landing	34
From landing to mill	41
Woods supervision	64
Part III. Manufacture	65
Mill pond	65
Sawmills	67
Sawmill lumber yards	80
Transportation to common carriers	86
Part IV. General cost factors	92
Overhead charges	92
Depreciation	95
Summary of the costs of typical operations	96
DEPARTMENT BULLETIN No. 441.—THE ACTION OF MANGANESE UNDER ACID AND NEUTRAL SOIL CONDITIONS.	
Effect of manganese on Arlington soil under acid conditions	2
Oxidative power of plats with and without manganese under acid conditions	5
Effect of manganese on Arlington soil under neutral conditions	6
Oxidative power of plats with and without manganese under neutral conditions	9
Summary	11

	Page.
DEPARTMENT BULLETIN No. 442.—POSSIBILITY OF THE COMMERCIAL PRODUCTION OF LEMON-GRASS OIL IN THE UNITED STATES.	
Soil and climatic requirements of lemon-grass	2
Propagation	3
Fertilizers and cultivation	3
Harvesting	4
Distillation	6
Varieties	7
Factors affecting the yield of lemon-grass oil	8
Factors affecting the citral content of lemon-grass oil	9
Solubility of lemon-grass oil in alcohol	10
Commercial possibilities	11
DEPARTMENT BULLETIN No. 443.—THE NEW MEXICO RANGE CATERPILLAR AND ITS CONTROL.	
General description of the range caterpillar	2
Where the range caterpillar occurs	3
Its economic importance and great abundance	3
Crops and grasses attacked	4
Character of the injury	4
Life history of the range caterpillar	6
Natural enemies of the range caterpillar	8
A wilt or rot disease	9
Destruction by hail	9
History of the range caterpillar	10
Control measures	11
DEPARTMENT BULLETIN No. 444.—FALSE BLOSSOM OF THE CULTIVATED CRANBERRY.	
Description of false blossom	1
Origin and distribution	3
Economic importance	4
Cause	4
Control	5
Summary	5
DEPARTMENT BULLETIN No. 445.—THE NAVEL ORANGE OF BAHIA WITH NOTES ON SOME LITTLE-KNOWN BRAZILIAN FRUITS.	
Origin and history of the navel orange of Bahia	1
Introduction of the Washington navel orange of Bahia into the United States	4
Culture of the navel orange in Bahia	7
Citrus fruits of Bahia other than the navel orange	15
Citrus fruits of the region around Rio de Janeiro	16
Miscellaneous fruits grown at Bahia	17
Some interesting fruits of Rio de Janeiro and vicinity	25
Fruits of the highlands and semiarid regions of Minas Geraes and Bahia	31
DEPARTMENT BULLETIN No. 446.—THE COST OF PRODUCING APPLES IN WENATCHEE VALLEY, WASH.	
Summary of results	2
Description of region	2
Method of survey	6
Orchard management	10
Handling the crop	26
Material costs	33
Fixed costs	33

Department Bulletin No. 447.—Water Penetration in the Gumbo Soils of the Belle Fourche Reclamation Project. Page.
Description of the gumbo soil of the Belle Fourche reclamation project 2
Water capacity of the gumbo soil 3
Productivity of the gumbo soil 3
Changes in the volume of the soil due to wetting and drying 3
Rate of movement of water in loose, saturated soil 4
Rate of movement of water in wet soil under field conditions 5
Penetration of water into dry soil in the field 6
Summary 11

Department Bulletin No. 448.—Separation and Identification of Food-coloring Substances.
General statements concerning reagents used in color analysis 2
Preliminary treatment of food products 4
Separation and purification of coloring substances 8
Identification of coloring substances 35

Department Bulletin No. 449.—A Study of the Electrolytic Method of Silver Cleaning.
Preliminary tests 3
Principle of the electrolytic method 4
Experimental study of the method 5
A household method 11
Summary 11

Department Bulletin No. 450.—Improvement of Ghirka Spring Wheat in Yield and Quality.
History and description of Ghirka spring wheat 2
Experiments 3
Comparative yields 3
Summary of yields 8
Milling and baking quality 9
Improvement by selection 12
Conclusions 18

INDEX.

	Bulletin No.	Page.
Abacaxi, description, quality, notes	445	19
Abíu, description, characteristics and uses	445	22
Achras Zapota, occurrence in Bahia, nature and value	445	18
Alfalfa—		
comparison with *Medicago falcata*	428	7,14–20, 24–27, 35, 37–65
hydridization with *Medicago falcata*, discussion	428	57–59
Medicago falcata, a yellow-flowered variety, bulletin by R. A. Oakley and Samuel Garver	428	1–70
mulch crop for apple orchard, management and cost in Washington	446	24–26
recovery after cutting, rate, comparison with *Medicago falcata*	428	40–41
relation of *Medicago falcata*	428	24–27
yellow-flowered. *See Medicago falcata.*		
Alpha-naphthol solution, reagent in color analysis, note	448	3
Aluminum, use in electrolytic cleaning of silver	449	3, 4, 5, 6, 7, 8, 9, 11
Ancylis nubeculana. See Leaf-sewer, apple.		
Annona sulzmanni, description and production in Brazil	445	19
Ants, enemies of apple leaf-sewer	435	11
Apple—		
box, standard, dimensions	446	26
leaf-sewer, bulletin by B. R. Leach	435	1–16
leaf-sewer. *See also* leaf-sewer, apple.		
orcharding, development in Washington, history	446	5–6
orchards, Pecos Valley, N. Mex., danger from codling moth, experiments and investigations	429	3–90
tree, age for bearing, different varieties	446	8
trees—		
defoliation by apple leaf-sewer, processes	435	2–4, 12
propping, methods, labor and cost	446	19–20
spraying for apple leaf-sewer, importance, and directions	435	11–12
Apples—		
cost of producing in Wenatchee Valley, Wash., bulletin by G. H. Miller and S. M. Thomson	446	1–35
cull, utilization as drier stock, suggestions	446	31
growing in Wenatchee Valley, Wash., practices and cost	446	2–35
harvesting and handling, operations and cost	446	26–35
picking, hauling, and packing, methods and cost	446	27–31
shipments from north and central Washington, 1905–1914	446	6
thinning, practices and cost	446	17–19
varieties grown in Wenatchee Valley, Wash., number trees and ages of each	446	7–8
yield of orchards in Wenatchee Valley, Wash	446	9
Araticum, swamp, occurrence, description and characteristics	445	33–34
Arlington farm—		
effect of Manganese sulphate on crop yield, acid soils, experiments	441	2–4, 11, 12
experiments on effect of manganese sulphate on crop yield, neutral conditions, 1913–1915	441	6–9, 12
Arsenical spray, use against range caterpillar	443	12
Autolysis, definition of term	433	8
Averrhoa carambola. See Carambola.		
Avocado, occurrence in Bahia, description, etc	445	18
Bacupari, description, origin, etc	445	30–31

	Bulletin No.	Page.
Bahia navel orange, with notes on some little-known Brazilian fruits, bulletin by P. H. Dorsett, A. D. Shamel and Wilson Popenoe	445	1–35
Barley—		
production failure at Archer, Wyo., 1913	430	30, 39
varietal experiments, Cheyenne experiment farm, 1913–1915	430	30–33, 39
BARROWS, H. P., and H. P. DAVIS, bulletin on "Judging the dairy cow as a subject of instruction in secondary schools"	434	1–20
Bean, soy. *See* Soy bean.		
Beans, yield, relation to manganese—		
experiments	441	9–11
on neutral soils, Arlington experiments, 1913–1915	441	6–9
Beef—		
autolysis experiments, methods, chemical studies and changes, etc	433	8–29, 99
bacteriological and historical studies in cold storage	433	30–32
changes during cold storage above freezing, bulletin by Ralph Hoagland, Charles N. McBryde, and Wilmer C. Powick	433	1–100
cold storage—		
chemical and physical studies, analysis methods	433	32–99
chemical studies, and changes	433	11–15, 17–29, 89–95, 99
composition of various muscle bundles	433	15–27, 97
effect on nutritive value	433	95–97, 99
experiments, methods, and studies	433	29–99
period	433	4, 99
physical characteristics	433	87–88, 99
practices	433	2–5
relation to organoleptic properties	433	88–89, 99
storing time at temperature above freezing, factors affecting	433	97–99
Bees—		
brood comb, appearance in sacbrood infection	431	12–13
larvæ—		
dead of sacbrood, appearance	431	13–24
description, and changes caused by sacbrood	431	6–24
sacbrood, bulletin by G. F. White	431	1–55
symptoms of sacbrood in colony	431	10–24
weakening of colony from sacbrood	431	30
Beetle—		
desert corn flea-beetle. *See* Flea-beetle, desert corn.		
five-spined engraver, injury to sugar pine	426	6
mountain pine, injury to sugar pine	426	6
red turpentine, injury to sugar pine	426	6
sugar-pine cone, injury to sugar pine	426	6
Belle Fourche reclamation project, water penetration in gumbo soils, bulletin by O. R. Mathews	447	1–12
BERRY, SWIFT, bulletin on "Lumbering in the sugar and yellow pine region of California"	440	1–99
Bibliography, potato-tuber moth, and other potato enemies	427	52–56
Birds, injury to sugar pine	426	5
Black brood, bees, notes	431	3–4
Bogs, cranberry, treatment for false blossom	444	5
Borer, flat-headed—		
injury to forest trees, nature	437	2
injury to sugar pine	426	6
Borers, flat-headed—		
affecting forest trees in the United States, bulletin by R. H. Burke	437	1–8
descriptions of various species	437	4–5
economic importance, food plants, life history, etc	437	1–3
structural characters, special	437	3–4

	Bulletin No.	Page.
Brazil, Bahia—		
climate, situation of orange orchards, and soil conditions	445	7–8
fruit cultivation, bulletin by P. H. Dorsett, A. D. Shamel, and Wilson Popenoe	445	1–35
Brazilian fruits, little known, and the navel orange of Bahia, bulletin by P. H. Dorsett, A. D. Shamel and Wilson Popenoe	445	1–35
Breadfruit, growing in Brazil, note	445	19
Bromin water, reagent in color analysis, note	448	3
Brush, disposal in apple orchards, labor, and cost	445	15
Buckwheat, production experiments, 1913–1915, Cheyenne experiment farm, yields, etc	430	38, 39
Bull, dairy, score card and requirements	434	7, 10–11
BURKE, H. E. bulletin on "Flat-headed borers affecting forest trees in the United States"	437	1–8
Buprestid larvæ, key to genera	437	5–8
See also Borers, flat-headed.		
Cabelluda, occurrence, description and characteristics	445	29
CAFFREY, D. J., and V. L. WILDERMUTH, bulletin on "The New Mexico range caterpillar and its control"	443	1–12
Caja spp., occurrence in Bahia, description and uses	445	18
Caju, characteristics, occurrence and uses	445	22–23
California—		
lumbering in the sugar and yellow pine region, bulletin by Swift Berry	440	1–99
pear orchards, treatment for insect pests, experiments	438	19–20
sugar pine and yellow pine region, topography, timber stands, etc	440	1–4
Cambuca, occurrence, description and characteristics	445	30
Camps, logging, types and management, California pine region	440	8–10
Carambola, occurrence in Bahia, description	445	18
Carbon, disulphid, use as potato fumigant, dosage, strength, use method	447	50, 51
Carica papaya. See Papaya.		
Carpocapsa pomonella. See Codling moth.		
Cashew, characteristics, occurrence and uses	445	22–23
Caterpillar, New Mexico range, and its control, bulletin by V. L. Wildermuth and D. J. Caffrey	443	1–12
See also Range caterpillar.		
Cedar, incense, stands in California pine region, volume and associated species	440	3–4
Cereal experiments—		
Cheyenne experiment farm, Archer, Wyo., bulletin by Jenkin W. Jones	430	1–40
Cheyenne farm, scope	430	9–12
Cereals, production in Great Plains, Agriculture Department publications	430	40
Cerodonta dorsalis, synonymy	432	2
See also Leaf-miner, spike-horned.		
Chætocnema ectypa. See Flea-beetle, desert corn.		
"Cherry of Brazil," description, uses, occurrence, etc	445	19–20
Cherry, Surinam, description and uses	445	22
Cheyenne—		
experiment district, description, history, soils, climate, vegetation, etc	430	2–8
Experiment Farm—		
Archer, Wyo., cereal experiments, bulletin by Jenkin W. Jones	430	1–40
location, description, scope, and methods of experiments	430	8–12, 38
Chrysocharus parksi, parasitic enemy of spike-horned leaf miner	432	16

	Bulletin No.	Page.
Chute-hauling, logs, management, equipment and cost	440	35–41
Chutes, lumber, construction crew, make-up, wages, and board, California pine region	440	37
Cirrospilus flavoviridis, parasitic enemy of spike-horned leaf-miner	432	15
Citral, importance in lemon-grass oil	442	5–6
Citron, occurrence in Bahia, description	445	15
Citrus spp., occurrences and uses	445	15
CLARK, J. ALLEN, bulletin on "Improvement of Ghirka spring wheat in yield and quality"	450	1–20
Climate—		
Bahia, Brazil, 1904–1912	445	7
sugar-pine range	426	2–3
Coal-tar dyes, identification methods	448	35–53
Codling moth—		
control in apple orchards, practices	446	21–23
life history in the Pecos Valley, N. Mex., bulletin by A. L. Quaintance and E. W. Geyer	429	1–90
seasonal history, studies in Pecos Valley, N. Mex	429	3–90
spring brood, emergence, oviposition, and generations, studies	429	3–79
studies—		
at Artesia, N. Mex	429	82–83
at Lincoln, N. Mex	429	83–86
at Roswell, N. Mex	429	4–82
at Santa Fe, N. Mex	429	86–87
Cold storage—		
beef, changes above freezing, bulletin by Ralph Hoagland, Charles N. McBryde, and Wilmer C. Powick	433	1–100
experiments with fresh beef, methods, etc	433	29–99
hygienic value	433	1
Coloring—		
extraction by immiscible solvents	448	22–34
food, separation, and identification, bulletin by W. E. Mathewson	448	1–56
natural substances, identification	448	54–55
Colors—		
analysis—		
reagents used, practices	448	2–4
solvents used	448	3–4
food, permitted, separation and identification	448	18–55
Conphthorus lambertianæ. *See* Beetle, sugar-pine cone.		
Coolers, meat refrigeration, kinds, care, temperature and humidity	433	2–4
Corn—		
flea-beetle, desert, bulletin by V. L. Wildermuth	436	1–23
See also Flea-beetle.		
oxidation of soil under acid conditions	441	5–6
plant, injury from desert corn flea-beetle, nature and extent	436	3–4
production tests and possibilities, Cheyenne Experiment Farm	430	37–38, 39
yield—		
relation of manganese, experiments	441	9–11
relation of manganese, neutral conditions, Arlington experiments, 1913–1915	441	6–9
relation of manganese sulphate, acid soils, experiments at Arlington farm, 1907–1912	441	2–4, 12
Cottonseed—		
acreage, production, and value, in boll-weevil States, 1909–1914	439	18–20
price comparison with soy beans, 1911–1914	439	19–20
"Countess's fruit," description and characteristics	445	31

	Bulletin No.	Page.
Cow, dairy—		
conformation and requirements	434	2–15
judging as a subject of instruction in secondary schools, bulletin by H. P. Barrows and H. P. Davis	434	1–20
score card, charts, etc.	434	2–15
Cowpeas—		
oxidation of soil under acid conditions	441	5–6
yield—		
relation of manganese, experiments	441	9–11
relation of manganese, neutral conditions, Arlington experiments, 1913–1915	441	6–9
relation of manganese sulphate, acid soils, experiments at Arlington farm, 1907–1912	441	2–4, 12
Cows, judging, practice by students of secondary schools, suggestions	434	16–20
Cranberry—		
bogs, treatment for false blossom	444	5
false blossom of cultivated variety, bulletin by C. L. Shear	444	1–8
See also False blossom.		
Crews, lumbering, make-up and wages, California pine region	440	6–8, 13–17, 18–20, 29–33, 45, 59–60, 61, 67, 68–69, 72, 76, 80
Cull, lumber, estimates for different species in California pine region	440	10
Cymbopogan citratus. *See* Lemon grass.		
Cyrtogaster occidentalis, parasitic enemy of spike-horned leaf-miner	432	15
Dacnusa, sp., parasitic enemy of spike-horned leaf-miner	432	16
Dairy cow—		
judging as subject of instruction in secondary schools, bulletin by H. P. Barrows and H. P. Davis	434	1–20
See also Cow, dairy.		
Davidson, W. M., R. L. Nougaret and E. J. Newcomer, bulletin on "The pear leaf-worm"	438	1–24
Davis, H. P., and H. P. Barrows, bulletin on "Judging the dairy cow as a subject of instruction in secondary schools"	434	1–20
Deadbrood bees, notes	431	3–4
Dendroctonus—		
monticolæ. *See* Beetle, mountain pine.		
volens. *See* Beetle, red turpentine.		
Desert corn—		
flea-beetle, bulletin by V. L. Wildermuth	436	1–23
See also Flea-beetle, desert corn.		
Diaulinopsis callichroma, parasitic enemy of spike-horned leaf-miner	432	15–16
Diaulinus websteri, parasitic enemy of spike-horned leaf-miner	432	15
Diseases injurious to sugar pine	426	5
Distichlis spicata, food of desert corn flea-beetle	436	4, 20
"Donkeys," types for logging, requirements, crews, and operation	440	28–33
Dorsett, P. H., A. D. Shamel, and Wilson Popenoe, bulletin on "The navel orange of Bahia, with notes on some little-known Brazilian fruits"	445	1–35
Dry farming, cereal experiments, Cheyenne experiment farm, bulletin by Jenkin W. Jones	430	1–40
Dry-land crop, Ghirka spring wheat, improvement in yield and quality	450	2–20
Dye, genipapo, note	445	21

	Bulletin No.	Page.
Dyes—		
food-coloring substances, separation and identification	448	1–56
numbers by which designated in published tables	448	56
Durability, sugar-pine superiority	426	12
Electrolytic—		
cleaning silver, principle of operation	449	4
cleaners, descriptions and tests	499	3–11
method of cleaning silver, study, bulletin by H. L. Lang and C. F. Walton, jr	449	1–12
Electrolysis, use in cleaning silver	449	1–12
Emmer, production tests, Cheyenne Experiment Farm, 1913–1915	430	25–26
Europe, importations of soy beans and products, 1908–1914, quantity and value	439	6–7
False blossom—		
control in cranberry plants	444	5
cranberry, bulletin by C. L. Shear	444	1–8
description, origin, and distribution	444	1–3
occurrence in cranberry plants, cause, discussion	444	4–5
Felling, crew make-up, operation and wages, California pine region	440	13–17
Fertilizers, use on lemon grass, experiments	442	3–4
Filters, virus, descriptions	431	27–30
Fir, white, stands in California pine region, volume and associated species	440	3–4
Fire, injury to sugar pine	426	4
Flat-headed borers. *See* Borers, flat-headed.		
Flax, varietal experiments, Cheyenne Experiment Farm, 1913–1915	430	33–36, 39
Flea-beetle—		
description, life history and habits	436	5–16
desert corn, bulletin by V. L. Wildermuth	436	1–23
distribution and economic importance	436	2–4
enemies	436	16–17
food plants	436	4–5
remedial measures	436	18–21
Flour, soy-bean, food value, comparison with other flours and corn meal	439	11–13
Flours, wheats grown in northern Great Plains, baking tests	450	11, 14
Flumes, lumber, requirements, construction, operation, and cost	440	89–92
Fomes—		
laricis, fungi enemy of sugar pine	426	5
pinicola, injury to sugar pine	426	5–6
Food plants, potato-tuber moth, list	427	14–15
Food-coloring substances, separation and identification, bulletin by W. E. Mathewson	448	1–56
Foods, colored, treatment for color analysis	448	4–8
Forest Service, protection to private lumber holdings, cost per acre	426	36
Forest trees, flat-headed borers affecting, bulletin by H. E. Burke	437	1–8
Forests—		
California National—		
fire protection, methods	426	34, 36
stumpage sales and prices	426	24
National, timber cutting, management, methods, utilization, etc	426	30–35
Foulbrood, comparison with sacbrood of bees	431	2–4
Frost, injury to sugar pine	426	5

	Bulletin No.	Page.
Frosts, killing, Cheyenne, Wyo., 1900-1915	430	7–8, 38
Fruit—		
industry, development in Washington, history	446	5–6
ranches, investments in Wenatchee Valley, Wash.	446	7
Fruits—		
Brazilian, little-known, and the navel orange of Bahia, bulletin by P. H. Dorsett, A. D. Shamel and Wilson Popenoe	445	1–35
grown at Rio de Janeiro, description, etc.	445	16–17, 25–31
miscellaneous, grown at Bahia, descriptions, etc	445	17–25
orange, grown at Bahia, description, etc	445	15, 17–25
Fruta—		
de conda, production in Brazil, note	445	19
de condessa, description and characteristics	445	31
Fumigant, carbon disulphid, dosage, strength, use method	427	50, 51
Fumigation, moth-infested potatoes, methods and fumigant	427	50, 51
Galls, forest trees, cause, discussion	437	3
Garver, Samuel and R. A. Oakley, bulletin on "*Medicago falcata*, a yellow-flowered alfalfa"	428	1–70
Genipap. *See* Genipapo.		
Genipapo—		
description, production, and uses in Brazil	445	21
liquor, characteristics, note	445	21
Geyer, E. W., and A. L. Quaintance, bulletin on "Life history of the codling moth in the Pecos Valley, N. Mex."	429	1–90
Ghirka—		
spring wheat—		
growing in northern Great Plains, experiments and comparisons with other wheats	450	3–18
history and description	450	2–3
improvement in yield and quality, bulletin by J. Allen Clark	450	1–20
wheat—		
agronomic data for product grown at Dickinson, N. Dak	450	16
milling and baking tests of flour	450	9–12, 17
Glyndon wheat, growing in northern Great Plains, experiments and comparison with other wheats	450	4–6
Gooseberry, occurrence in Bahia, description	445	18
"Gourd of the campo," description, occurrence and characteristics	445	32
Graf, J. E., bulletin on "The potato-tuber moth"	427	1–56
Grain—		
crops, injury by range caterpillar in New Mexico	443	4
plants, injury by spike-horned leaf-miner, nature	432	7–9
Grass, lemon. *See* Lemon grass.		
Grasses—		
hosts of desert corn flea-beetle	436	4, 20–21
injury by spike-horned leaf-miner, nature	432	7–9
New Mexico, destruction by range caterpillar	443	4
varieties, natives of Wyoming	430	3
Gravata, description, characteristics, occurrence, etc	445	21–22
Grazing, sheep and goats, injury to sugar pine	426	5
Grumichama, description, occurrence, uses and habits	445	19–20
Grumixama, description, uses, occurrence, etc	445	19–20
Guabiroba, occurrence, description and characteristics	445	29–30
Guava, occurrence in Bahia, description and uses	445	18–19
Guinea oil palm, occurrence, growth habits, fruit and uses	445	24–25
Gumbo soil—		
mechanical analysis, water capacity, productivity and changes due to wetting and drying	447	2–4
productivity at Belle Fourche reclamation project	447	3

	Bulletin No.	Page.
Gumbo soils, water penetration on the Belle Fourche reclamation project, bulletin by O. R. Mathews	447	1–12
Gymnonychus californicus. *See* Leaf-worm, pear.		
Harvesting—		
apples, operations, handling and cost, Washington	446	26–35
lemon grass, practices and experiments	442	4–6
Hauling—		
apples, methods and cost	446	28, 30–31
logs—		
from landing to mill, methods, cost and operation	440	41–64
from stump to mill, processes, methods, operation and cost	440	18–64
from yard to landing, methods, cost and operation	440	34–41
Hay plant—		
drought-resistant, *Medicago falcata*	428	45–47
Medicago falcata, introduction, nature and value	428	2–65
Haynes wheat—		
growing in northern Great Plains, experiments and comparisons with other wheats	450	4–6
milling and baking tests of flour	450	9–12
Hemileuca oliviae. *See* Range caterpillar.		
HOAGLAND, RALPH, CHARLES N. MCBRYDE, and WILMER C. POWICK, bulletin on "Changes in fresh beef during cold storage above freezing"	433	1–100
Honey, treatment for sacbrood virus, experiments	431	40–43
HOOD, S. C., Bulletin on "Possibility of the commercial production of lemon-grass oil in the United States"	442	1–12
Horses, skidding teams, cost, equipment, and deterioration	440	18–20
Hybridization, alfalfa with *Medicago falcata*, value, and methods	428	58–59
Hydrazin sulphate solution, reagent in color analysis note	448	3
Imbu, occurrence, description, growth habits and characteristics	445	34–35
Incubation, meat, effect for various periods	433	10–11, 27–29, 99
Insects—		
control in sugar pines, methods and cost per acre	426	7
varieties, injury to sugar pine	426	6
Insurance, lumber, rates in California pine region	440	93–94
Ionone, manufacture from lemon-grass oil, notes	442	1, 11
Ips confusus, injury to sugar pine	446	6
Irrigation—		
apple orchards, operations, labor and cost	446	15–17
gumbo soils, penetration of water in dry and wet soils, experiments, etc	447	3–11
Jaboticaba, description, growth habits, occurrence, and uses	445	25–29
Jack fruit, uses in Brazil	445	19
Jak, Malayan, uses in Brazil	445	19
Japan, soy-bean production, exports and imports, 1911–1914	439	4–5
Joazeiro, occurrence, growth habits and fruit characteristics	445	35
Johnson grass, host of desert corn flea-beetle	436	4, 20–21
JONES, JENKIN W., bulletin on "Cereal experiments on the Cheyenne experiment farm, Archer, Wyo."	430	1–40
Kubanka wheat—		
growing in northern Great Plains, experiments and comparison with other wheats	450	4–6
milling and baking tests of flour	450	9–11

	Bulletin No.	Page.
Labor—		
fruit ranches, central Washington, operations and wages	446	9–10
lumbering operations in California pine region, management, sources, and wages	440	5–8, 16, 19–20, 21, 29–30, 37, 45, 59–60, 61, 67, 68–69, 72, 76, 80, 94
Land, National Forest, management	426	30–35
LANG, H. L., and C. F. WALTON, JR., bulletin on "A study of electrolytic method of silver cleaning"	449	1–12
Laranja—		
da terra, use in Brazil as budding stock	445	16
lima, occurrence in Bahia, description	445	15
LARSEN, LOUIS T., and T. D. WOODBURY, bulletin on "Sugar pine."	426	1–40
Larvae, bee, description and changes caused by sacbrood	431	6–24
LEACH, B. R., bulletin on "The apple leaf-sewer"	435	1–16
Leaf-folder, apple. *See* Leaf-sewer, apple.		
Leaf-miner, spike-horned—		
an enemy of grains and grasses, bulletin by Philip Luginbill and T. D. Urbahns	432	1–20
control measures	432	16
description, distribution and life history	432	5–7
enemies	432	15–16
history, and food plants	432	2–5
rearing methods	432	14–15
Leaf-sewer, apple—		
bulletin by B. R. Leach	435	1–16
description, life history and habits	435	4–10
enemies	435	11
history, distribution and feeding habits	435	2–4
remedial measures	435	11–12
Leaf-worm, pear—		
bulletin by R. L. Nougaret, W. M. Davidson, and E. J. Newcomer	438	1–24
control by spraying with lead arsenate	438	21–22
control measures, experiments	438	17–22
description, habits and life history	438	4–17
history, distribution and food plants	438	1–3
parasitic enemies, discussion	438	17–18
Legumes, varieties, natives of Wyoming	430	3
Lemon grass—		
charasteristics, importance in perfume industry	442	1
citral content—		
and oil yields of different varieties	442	7–8
factors affecting	442	9–10
remarks	442	6
distillation	442	6
fertilizer requirements	442	3–4
growing for oil, experiments by Department, cost and returns	442	2–6, 11–12
oil—		
commercial production in United States, possibility, bulletin by S. C. Hood	442	1–12
yields of fresh and dried	442	6, 8
propagation, cultivation and harvesting	442	3–6
"Lemon of the forest," description and characteristics	445	32
Lemons, sweet and sour, occurrence in Bahia, description	445	15
Light, requirements of trees in list	426	8
Lightning, injury to sugar pine	426	4, 5
Lime—		
acre requirement, various crops, experiments	441	4, 7, 12
occurrence in Bahia, description	445	15
"Lime-orange," occurrence in Bahia, description	445	15
Lime-sulphur spray, use in apple orchards, time and purpose	446	21

	Bulletin No.	Page.
Limoa do matto, description and characteristics	445	32
Locomotives, logging railroad, types, cost, and loads	440	56–58
Log ponds, construction, size and cost, California pine region	440	65–67
Logs—		
hauling from stump to mill, processes, methods, operations and cost	440	18–64
loading on trucks, methods, equipment and cost	440	41–44
yarding—		
big-wheel method, equipment, cost and operation	440	20–23
overhead method, equipment, cost, and operation	440	33–34
steam-donkey method, equipment, cost and operation	440	23–33
Logging—		
blocks, prices	440	27
charges overhead, California pine region	440	92–95
crews—		
make-up and wages in California pine region	440	7–8
wages in California pine region	440	7
operations, requirements, etc., California pine region	440	13–65
sugar pine and yellow pine, methods and cost	426	12–13
use of term	440	13
Lophyrus. See Saw-fly.		
LUGINBILL, PHILIP, and T. D. URBAHNS, bulletin on "The Spike-horned leaf-miner, an enemy of grains and grasses"	432	1–20
Lumber—		
cull, discounts for different species in California pine region	440	10
handling in sawmill lumber yards, practices in California pine region	440	80–86
inclines, requirements, construction and cost	440	88–89
pine, production in California pine region, operations, volume, labor, etc	440	3–99
sugar-pine—		
amount used, various industries, 1910	426	20–22
depreciation in seasoning	426	18–20
weight per 1,000 feet	426	11
yields, values and grades	426	16–20
transportation from mill to common carrier, methods and cost, California pine region	440	86–92
yards, sawmill types, equipment, and cost of handling lumber	440	80–86
Lumbering—		
crews, housing, practices, equipment and cost in California pine region	440	8–10
equipment, depreciation, estimates	440	95–96
sugar pine and yellow pine region of California, bulletin by Swift Berry	440	1–99
wages in California pine region	440	7–8
Manchuria, production of soy beans and products, methods, yields, exports, 1909–1913	439	2–4, 5
Manga de rosa, description and value	445	23–24
Manganese—		
action under acid and neutral soil conditions, bulletin by J. J. Skinner and F. R. Reid	441	1–12
effect on crop yields, neutral conditions, experiments at Arlington farm, 1913–1915	441	6–9, 12
Mango—		
occurrence, growth habits, uses, and varieties	445	23–24
rose, description and value	445	23–24
MATHEWS, O. R., bulletin on "Water penetration in the gumbo soils of the Belle Fourche Reclamation Project"	447	1–12
MATHEWSON, W. E., bulletin on "Separation and identification of food-coloring substances"	448	1–56

	Bulletin No.	Page.
McBryde, Charles M., Ralph Hoagland, and Wilmer C. Powick, bulletin on "Changes in fresh beef during cold storage above freezing"	433	1–100
Meal, soy-bean—		
fertilizer, value comparison with other fertilizers	439	14–15
food value, comparison with various flours and corn meal	439	11–13
use as stock feed, comparison with other feeds	439	13–14
Meat, ripening in cold storage, methods	433	5
Meats, cold-storage investigations, purpose and plan	433	5–8
Medicago falcata—		
agricultural history and characteristics	428	33–51
botanical history, description and relationship	428	8–33
comparison with alfalfa	428	7, 14–20, 24–27, 37–65
cultural investigations, hybridization, etc	428	51–65
distribution, climatic and soil requirements, etc	428	5–8
introduction and history	428	1–5
names	428	34–35
yellow-flowered alfalfa, bulletin by R. A. Oakley and Samuel Garver	428	1–70
Melanophila gentilis. See Borer, flat-headed.		
Metals, tarnishing, processes and nature	449	4
Milk, vegetable, manufacture from soy beans	439	9
Miller, G. H., and S. M. Thomson, bulletin on "The cost of producing apples in Wenatchee Valley, Wash."	446	1–35
Millet, foxtail, production experiments, Cheyenne experiment farm, 1913–1915, yields, etc	430	36–37, 39
Milling, sugar pine, mill types, cost, cut per year, and lumber grade product	426	13–16
Moisture, requirements of trees in list	426	7
Montana, wheat-growing experiments	450	4–18
Morse, W. J., and C. V. Piper, bulletin on "The soy bean, with special reference to its utilization for oil, cake, and other products"	439	1–20
Moth—		
apple leaf-sewer, description, life cycle and habits	435	5–10
codling. *See* Codling moth.		
potato-tuber—		
artificial control	427	48–51
bulletin by J. E. Graf	427	1–56
classification, synonymy, and description	427	9–14
dissemination, mortality, increase rate	427	31–32
economic importance	427	6–8, 51
enemies and checks	427	32–48
food plants, list	427	14–15
history—		
and habits	427	15–32
distribution and origin	427	1–4, 51
injuries, nature and methods	427	4–6
Mulch crops, apple orchards in Washington, management and cost	446	24–26
Navel orange—		
of Bahia, with notes on some little-known Brazilian fruits, bulletin by P. H. Dorsett, A. D. Shamel, and Wilson Popenoe	445	1–35
See also Orange, navel.		
Neurepyris sp. enemy of desert corn flea-beetle	436	17
New Mexico—		
pastures, destruction by range caterpillar	443	4
Pecos Valley, life history of the codling moth, bulletin by A. L. Quaintance and E. W. Geyer	429	1–90
range caterpillar—		
and its control, bulletin by V. L. Wildermuth and D. J. Caffrey	443	1–12
See also Range caterpillar.		

	Bulletin No.	Page.
NEWCOMER, E. J., R. L. NOUGARET and W. M. DAVIDSON, bulletin on "The pear leaf-worm"	438	1–24
North Dakota, wheat growing experiments	450	4–18
NOUGARET, R. L., W. M. DAVIDSON and E. J. NEWCOMER, bulletin on "The pear leaf-worm"	438	1–24
OAKLEY, R. A., and SAMUEL GARVER, bulletin on "*Medicago falcata*, a yellow-flowered alfalfa"	428	1–70
Oats—		
production, failure at Archer, Wyo., 1913	430	26, 39
varietal experiments, Cheyenne experiment farm, 1913–1915	430	26–30, 39
Oil—		
lemon-grass—		
citral content, importance	442	5–6
commercial production in United States, possibility, bulletin by S. C. Hood	442	1–12
loss by drying and distillation	442	6–7
solubility in alcohol	442	10–11
uses and sources of production	442	1–2
palm, Guinea, occurrence, growth habits, fruit and uses	445	24–25
soy-bean—		
extraction methods, United States and Europe	439	9–11
uses, experiments	439	15–16
Opius—		
aridus, parasitic enemy of spike-horned leaf-miner	432	16
dimidiatus, parasitic enemy of spike-horned leaf-miner	432	16
Orange—		
bitter or sour, occurrence in Bahia, description	445	15
Natal, occurrence in Brazil, description, etc	445	16, 17
navel—		
and other fruits, bulletin by P. H. Dorsett, A. D. Shamel, and Wilson Popenoe	445	1–35
Bahia and California grown, value comparison, analyses	445	13–15
introduction into United States	445	4–6
origin, history, culture, and extent of industry in Bahia	445	1–2, 3–4, 7–15
propagation in Bahia, budding, planting, etc., methods	445	9–11
Pera, occurrrence in Brazil, description, etc	445	17
Selecta—		
cultivation in Bahia, and description	445	2–3
occurrence in Brazil, description	445	16–17
trees, Bahia, insect enemies and diseases	445	11–12
Washington navel, adoption of name	445	5
Oranges—		
Bahia, crop-ripening seasons yield, selling methods, price, shipping adaptability	445	12–13
growing in Rio de Janeiro, varieties, acreage, methods, yields, etc	445	16–17
navel, distribution in California and Florida	445	5–6
Orchard, apple, depreciation	446	2
Orcharding, apple—		
costs, and labor, per acre and per box, Wenatchee Valley, Wash	446	33–35
Washington, Wenatchee Valley, practices, cost, etc	446	2–35
Orchards—		
apple, cultivation, irrigation and spraying, practices in Wenatchee Valley, Wash	446	10–26
management, operations and cultivation, practices in Wenatchee Valley, Wash	446	10–26
orange, in Bahia, situation and soil conditions	445	7–8
Pecos Valley, N. M., danger from codling moth, experiments and investigations	429	1–90

	Bulletin No.	Page.
Oxidation—		
manganese, various crops, neutral conditions	441	9–11
manganese-treated and check plats, various crops, acid conditions	441	5–6, 12
Oxycoccus macrocarpus. *See* False blossom.		
Packing, apples, for market, practices in Wenatchee Valley, Wash	446	28–30
Palm, dendé, occurrence, growth habits, fruit, and uses	445	24–25
Papaya, occurrence in Bahia, description, uses, and value	445	18
Parasites, potato-tuber moth, list, description, habits and work	427	32–47
Pastures, range. destruction by range caterpillar in New Mexico	443	4
Pear—		
leaf-worm—		
bulletin by R. L. Nougaret, W. M. Davidson, and E. J. Newcomer	438	1–24
See also Leaf-worm, pear.		
"of the campo," occurrence, description and characteristics	445	32
orchards—		
Pecos Valley, N. Mex., danger from codling moth, experiments and investigations	429	1–90
treatment for insect pests, experiments	438	19–22
sawfly. *See* Leaf-worm, pear.		
trees, injury by leaf-worm, nature	438	3–4
Pediculoides sp., enemy of desert corn flea-beetle	436	17
Pera do campo, occurrence, description and characteristics	445	32
Perfumery, manufacture from lemon-grass oil, notes	442	1, 11
Peridermium harknessii, injury to sugar pine	426	5
Persea americana, occurrence in Bahia, etc	445	18
Phthorimaea operculella. *See* Moth, potato-tuber.		
Phyllanthus acida, occurrence in Bahia, etc	445	18
Picking apples, management, operations, and cost in Wentachee Valley, Wash	446	27
"Pickled brood"—		
bees, notes	431	4–6
See also Sacbrood.		
Pine—		
lumbering in sugar and yellow pine region of California, bulletin by Swift Berry	440	1–99
sugar—		
age, growth, and yield	426	24–30
altitude and climate of range	426	2–3
appearance and structure of wood, comparisons, etc	426	10–12
bulletin by Louis T. Larsen and T. D. Woodbury	426	1–40
diameter and volume growth, based on age	426	26–28
economic importance	426	1–2
geographical and commercial range	426	2–3
grades	426	40
habits, root system, bark, leaves, flowers, and seed	426	3–4
height growth, based on age	426	24–26
logging and milling	426	12–16
lumber grades, comparison with yellow pine lumber, California pine region	440	12–13
market demands and uses	426	20–22
preservative treatment, note	426	12
size, longevity, susceptibility to injury and disease	426	4–7
species, moisture, soil, and light requirements	426	7–8

	Bulletin No.	Page.
Pine—Continued.		
sugar—Continued.		
stands, California pine region, volume and associated species	440	3–4
types, description, occurrence, etc	426	10
volume tables, California National Forests	426	37–39
yellow—		
lumber grades, comparison with sugar pine lumber, California pine region	440	12–13
stands in California pine region, volume and associated species	440	3–4
Pineapple, Bahia, description, quality, and marketing practices	445	19
Pineapples, occurrence in Bahia, description and value	445	19
Pines, sugar—		
and other, identification key	426	39
forest types	426	9–10
Pinha, occurrence, description, and characteristics	445	33
Pinus lambertiana. *See* Pine, sugar.		
Piper, C. V., and W. J. Morse, bulletin on "The soy bean, with special reference to its utilization for oil, cake, and other products"	439	1–20
Pissodes yosemitei, injury to sugar pine	426	6
Pitanga, description and uses	445	22
Pitomra, description, occurrence, and propagation	445	20–21
Polycystus foersteri, parasitic enemy of spike-horned leaf-miner	432	16
Polyporus volvatus, injury to dead sugar pine trees	426	6
Ponds, sawmill, construction, size and cost, California pine region	440	65–67
Potassium persulphate, reagent in color analysis, note	448	3
Potato, tuber moth, bulletin by J. E. Graf	427	1–56
Potatoes—		
fumigation for tuber-moth infested, before storage	427	50, 51
oxidation of soil under acid conditions	441	5–6
planting, depth, time, etc., for tuber-moth control, experiments	427	48–50, 51
yield—		
manganese neutral conditions, Arlington experiments, 1913–1915	441	6–9
manganese sulphate acid soils, experiments at Arlington farm, 1907–1912	441	2–4, 12
with and without manganese, experiments	441	9–11
Powick, Wilmer C., Ralph Hoagland, and Charles N. McBryde, bulletin on "Changes in fresh beef during cold storage above freezing"	433	1–100
Precipitation—		
Cheyenne, Wyo., 1900–1915	430	3–6, 38
northern Great Plains, 1908–1914	450	7–8
Propagation, lemon grass, method	442	3
Proso, production experiments, Cheyenne experiment farm, 1913–1915, yields, etc	430	36–37, 39
Pruning, apple trees, labor and cost	446	14
Pseudomphale ancylae, enemy of apple leaf-sewer	435	11
Psidium guagava, occurrence in Bahia, description and uses	445	18–19
Quaintance, A. L., and E. W. Geyer, bulletin on "Life history of the codling moth in the Pecos Valley, N. Mex."	429	1–90
Racupari, occurrence, description, and characteristics	445	30–31
Railroads—		
logging, types, construction, cost and maintenance	440	46–64
wages in California pine region	440	7
Ranch, fruit, investments in Wenatchee Valley, Wash	446	7

	Bulletin No.	Page.
Range—		
burning for destruction of range caterpillar	443	11
caterpillar—		
damage to grasses and crops, nature and extent	443	4–6
description, occurrence and economic importance.	443	2–4
enemies, and disease	443	8–9
history and control	443	10–12
life history	443	5–7
New Mexico, and its control, bulletin by V. L. Wildermuth and D. J. Caffrey	443	1–12
Reageants, food-color analysis	448	3
Reduviolus ferus, enemy of desert corn flea-beetle	436	17
Refrigeration, meats, systems, numbers, kinds, care, and temperature of coolers	433	2–5
Reid, F. R., and J. J. Skinner, bulletin on "The action of Manganese under acid and neutral soil conditions"	441	1–12
Reproduction—		
sugar-pine, conditions retarding	426	8–9
tree, in California national forests, methods	426	34–35
Rheedi abrasiliensis, description and food use	445	30–31
Rose-apple, occurrence in Bahia	445	18
Russia, precipitation and temperature at several points, comparison with Northwestern States	428	5
Rye—		
oxidation of soil under acid conditions	441	5–6
yield—		
manganese sulphate, acid soils, experiments at Arlington farm, 1907–1912	441	2–4, 12
manganese sulphate, neutral conditions, Arling experiments, 1913–1915	441	6–9
with and without manganese, experiments	441	9–11
Rysting wheat—		
growing in northern Great Plains, experiments and comparison with other wheats	450	4–6
milling and baking tests of flour	450	9–12
Sacbrood—		
bulletin by G. P. White	431	1–55
cause, discussion	431	24–30
combating, suggestions	431	50–52
comparison with foulbrood of bees	431	2–4
diagnosis and prognosis	431	48–50
germ, filtering experiments	431	27–30
inoculation of bees, virus required, methods, etc	431	31–34
nature, historical notes, etc	431	1–6
symptoms	431	10–24
transmission, modes	431	46–48
virus—		
persistence	431	34–46
virulence in honey	431	40–41
Salt grass, food plant of desert corn flea-beetle	436	4, 20
Sapodilla, occurrence in Bahia, description and value	445	18
Saunders, William, introducer of navel oranges into United States	445	4–6
Sawfly—		
injury to sugar pine	426	6
pear. *See* Leaf-worm, pear.		
Sawmills—		
camps, types, cost, and management	440	9–10
crews—		
make-up wages, work, and equipment for different mills	440	68–80
wages in California pine region	440	8
overrun, California pine region	440	12
types—		
construction, cost, and operation, California pine region	440	67–80
in California pine region	440	4–5

	Bulletin No.	Page.
SCHNEIDER, REV. F. I. C., shipment of orange trees, Bahia to United States	445	6
Schools, secondary, judging dairy cow as subject of instruction, bulletin by H. P. Barrows and H. P. Davis	434	1–20
Seed—		
alfalfa—		
comparison with *Medicago falcata*	428	14–17
production, description, etc	428	14–17
sugar pine, gathering, yield, germination, etc	426	8–9
Seedlings, production for forest replanting in California, cost, etc	426	35
Shade, endurance by trees in list	426	8
SHAMEL, A. D., P. H. DORSETT, and WILSON POPENOE, bulletin on "The navel orange of Bahia, with notes on some little-known Brazilian fruits"	445	1–35
SHEAR, C. L., bulletin on "False blossom of the cultivated cranberry"	444	1–8
Shingles, hand-split, use and value of sugar pine	426	22
Sholteek. *See Medicago falcata.*		
Shooks, apple-box, buying, hauling,, practices and cost	446	26–27
Sickle-podded alfalfa. *See Medicago falcata.*		
Silver—		
cleaning—		
practices and requirements	449	2–3
study of the electrolytic method, bulletin by H. L. Lang and C. F. Walton, jr	449	1–12
tarnish, causes and removal	449	2–3
Silvical requirments, sugar pine	426	7–8
Skidding—		
crew make-up, and wages, California pine region	440	18–20
logs, practices in California pine region	440	18–20
SKINNER, J. J., and F. R. REID, bulletin on "The action of manganese under acid and neutral soil conditions"	441	1–12
Slash, sugar pine, burning for insect control	426	7
Snow, injury to sugar pine	426	5
Sodium—		
hydrosulphite solution, reagent in color analysis, note	448	3
nitrate, reagent in color analysis, note	448	3
Soil—		
gumbo—		
mechanical analysis, water capacity, productiveness and changes due to wetting and drying	477	2–4
productivity at Belle Fourche reclamation project	477	3
requirements of trees in list	426	7
Soils—		
gumbo—		
Belle Fourche reclamation project, water penetration, bulletin by O. R. Mathews	447	1–12
water penetration in the Belle Fourche reclamation project, bulletin by O. R. Mathews	447	1–12
water movements in wet and dry	447	4–11
Solvents, food-coloring, use in color analysis	448	3–4
Sorghum halepense—		
food plant of desert corn flea-beetle	436	4, 20–21
Sorghums—		
injury by desert corn flea-beetle, note	436	3
production failure, Cheyenne experiment farm, 1913–1915	430	37, 39
South Dakota, wheat growing experiments	450	4–18
Soy bean—		
(and products), importations to Europe, 1908–1914, quantity and value	439	6–7
food uses and value	439	12–13

	Bulletin No.	Page.
Soy bean—Continued.		
use and value as coffee substitute	439	13
use and value as cottonseed substitute	439	1–2
with special reference to its utilization for oil, cake, and other products	439	1–20
Soy beans—		
American grown, possibility of industry development	439	18–20
analyses of important varieties, various States	439	16–17
(and products)—		
imports into United States, 1910–1915, quantity and value	439	9
production in Japan, exports and imports, 1911–1914	439	4–5
production in Manchuria, exports and imports, 1909–1913	439	2–4, 5
European prices per ton	439	19–20
growing importance of industry in cotton belt	439	20
production in United States, soil and climatic adaptation, seed yield, cost, and price	439	7–8
Soy-bean—		
cake, value as stock and poultry feed	439	8–9, 13–14
oil, uses and value	439	8
Spiders, enemies of potato-tuber moth	427	48
Spike-horned leaf-miner—		
an enemy of grains and grasses, bulletin by Philip Luginbill and T. D. Urbahns	432	1–20
See also Leaf miner, spike-horned.		
Spondias spp., occurrence in Bahia, etc	445	18
Spray—		
arsenical—		
use against apple leaf-sewer	435	11–12
use against desert corn flea-beetle, note	436	18, 19
use against range caterpillar	443	12
codling-moth, preparation and application	446	21–23
"dormant" for orchard trees, preparation and application	446	21
Spraying—		
apple trees, practices, labor and cost	446	20–23
cereal crops for control of range caterpillar	443	12
management for control of pear leaf-worm	438	19–22
Sprays—		
apple-orchard, application, labor, equipment and cost	446	21–23
formulas for use against pear leaf-worm, experiments	438	19–22
use against—		
codling moth, aid in control of pear leaf-worm	438	19–20
pear thrips, aid in control of pear leaf-worm	438	19
Squirrels, injury to sugar pine	426	5
Storage, time for beef in coolers	433	4, 99
Straw, soy-bean, value as fertilizer	439	19, 20
Stumpage, sugar pine, prices and value	426	23–24
Stumps—		
blasting, requirements and cost, California pine region	440	49
logging regulations in California pine region	440	10–11
Sudan grass, injury by desert corn flea-beetle, note	436	3
Sugar pine—		
bulletin by Louis T. Larsen and T. W. Woodbury	426	1–40
See also Pine, sugar.		
Sugar-apple, occurrence, description and characteristics	445	33
Sulphate, manganese, effect on yields of various crops, acid soils, experiments at Arlington farm, 1907–1912	441	2–4, 11, 12
"Swamp araticum," occurrence, description and characteristics	445	33–34

149354—20——3

	Bulletin No.	Page.
Tamarind, Indian, occurrence at Bahia, description and use	445	18
Tamarindus indica. *See* Tamarind, Indian.		
Tangerine, occurrence in—		
Bahia, description	445	15
Rio de Janeiro, note	445	17
Tarnish, metal, nature and removal	449	2–3, 4
Taxes, timber standing, note	440	92–93
Teachers, agriculture, judging dairy cow as subject of instruction	434	1–20
Temperature, Cheyenne, Wyo., April to July, 1900–1915	430	7
Thistles, varieties, natives of Wyoming	430	3
THOMSON, S. M., and G. H. MILLER, bulletin on "The cost of producing apples in Wenatchee Valley, Wash."	446	1–35
Timber—		
cutting on National Forests, management, methods, utilization, etc	426	30–35
quality, mill tally, California pine region	440	12–13
stands, taxes, note	440	92–93
sugar-pine, quality, weight, strength, etc., comparison with other pines	426	10–12
tracts, supervision for logging, practices and cost in California pine region	440	64–65
utilization in California pine region, practices	440	10–11
Timberlands, private, management	426	35–36
Timothy, yield—		
relation to manganese, experiments	441	9–11
relation to manganese, neutral conditions, Arlington experiments, 1913–1915	441	6–9
Trametes pini, fungi enemy of sugar pine	426	5
Trees, forest, flat-headed borers affecting, bulletin by H. E. Burke	437	1–8
Trestles, logging railroad, construction and cost	440	53
Trucks—		
hauling logs to mill, types, construction, and management	440	44–46
logging railroad, types, cost and equipment	440	58–64
Tubers, experiments in moth control by care in planting, etc	427	48–50, 51
Udder, dairy cow, conformation and types	434	13–14
URBAHNS, T. D., and PHILIP LUGINBILL, bulletin on "The spike-horned leaf-miner, an enemy of grains and grasses"	432	1–20
Virus—		
filters, descriptions	431	27–30
sacbrood—		
destruction, means and methods	431	34–43
persistence	431	34–46
resistance to carbolic acid, experiments	431	44–46
resistance to heat and sunlight, experiments	431	34–44
WADDELL, REV. W. A.—		
statement on the navel orange of Bahia	445	2
work for navel orange	445	6
Wages—		
apple orcharding, Wenatchee Valley, Wash	446	10
lumbering operations in California pine region	440	7–8, 16, 19–20, 21, 29–30, 37, 45, 59–60, 61, 67, 68, 69, 72, 76, 80, 94
WALTON, C. F., Jr., and H. L. LANG, bulletin on "A Study of the electrolytic method of silver cleaning"	449	1–12

	Bulletin No.	Page.
Washington—		
apple growing—		
cost of producing in Wenatchee Valley, bulletin by G. H. Miller and S. M. Thomson	446	1–35
region, topography, climate, and agricultural conditions	446	2–5
pear orchards, treatment for insect pests, experiments	438	21–22
Wenatchee Valley, climate, soil, and agricultural conditions	446	2–5
Water, penetration in the gumbo soils of the Belle Fourche reclamation project, bulletin by O. R. Mathews	447	1–12
Weevil, injury to sugar pine	426	6
Wheat—		
Ghirka spring, improvement in yield and quality, bulletin by J. Allen Clark	450	1–20
Ghirka. *See also* Ghirka wheat.		
oxidation of soil under acid conditions	441	5–6
spring, varietal experiments, Cheyenne Experiment Farm	430	17–24, 38–39
winter, varietal experiments, Cheyenne Experiment Farm, 1913–1915	430	12–17, 38–39
yield—		
relation to manganese, experiments	441	9–11
relation to manganese sulphate, acid soils experiments at Arlington farm, 1907–1912	441	2–4, 12
relation to manganese sulphate, neutral conditions, Arlington experiments, 1913–1915	441	6–9
yields of different varieties in northern Great Plains, experimental work	450	8–9
Wheats—		
dry-land, growing in northern Great Plains, experiments	450	4–11
yield, comparisons, at Cheyenne Experiment Farm, 1913–1915	430	24, 38–39
WHITE, G. F., bulletin on "Sacbood"	431	1–55
WILDERMUTH, V. L.,—		
and D. J. CAFFREY, bulletin on "The New Mexico range caterpillar and its control"	443	1–12
bulletin on "The desert corn flea-beetle"	436	1–23
Wind—		
injury to sugar pine	426	4, 5
velocity, Cheyenne, Wyo., April to July, 1900–1915	430	6
Wire rope, prices for use in logging	440	26
Wisconsin, cranberry crops, injury from false blossom	444	4
Witches' broom, injury to sugar pine	426	5
Wood, sugar-pine, appearance and structure, comparisons	426	10
WOODBURY, T. D., and LOUIS T. LARSEN, bulletin on "Sugar pine"	426	1–40
Wyoming—		
Archer, cereal experiments on Cheyenne Experiment Farm, bulletin by Jenkin W. Jones	430	1–40
wheat growing, experiments	450	4–18
Yarding—		
crew, make-up, California, pine region	440	29–30
engines, prices	440	25
logs, methods in California pine region	440	18–24
Zinc, use in electrolytic cleaning of silver	449	3, 5, 6, 7, 8, 9, 11

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SUGAR PINE

By Louis T. Larsen, *Forest Examiner*, and T. D. Woodbury, *Assistant District Forester*

CONTENTS.

	Page.
Importance of sugar pine	1
Geographical and commercial range	2
Habit and root system	3
Bark, leaves, flowers, and seed	3
Size and longevity	4
Susceptibility to injury and disease	4
Silvical requirements	7
Reproduction	8
Forest types	9
The wood	10
Logging	12
Milling	13
Values and grades of lumber	16
Markets	20
Uses	20
Stumpage prices	23
Growth and yield	24
Management	30
Management of private timberlands	35
Appendix	37

IMPORTANCE OF SUGAR PINE.

Sugar pine (*Pinus lambertiana* Dougl.) was first recognized by David Douglas, of the London Horticultural Society, on the headwaters of the Umpqua River in Oregon, October 26, 1826. The tree was given the specific name *lambertiana* in honor of Douglas's friend Aylmer Bourke Lambert, a founder and vice president of the Linnean Society of London and the author of a prominent work on pines.

Sugar pine is the most valuable commercial timber tree on the Pacific coast, and its relative value among all the conifers of the world is very high. This is attributable partly to the characteristic straightness and unusual clear length of the trees and partly to the excellent physical qualities of the wood, which adapt it admirably to high-class uses in manufacture and trade.

Commercially, sugar pine may be considered, like the redwood, as essentially a California tree. Although it occurs in southern Oregon and in Lower California, it is relatively unimportant in both of these regions. The total stand in Oregon is estimated at approximately 3 billion

NOTE.—This bulletin describes the sugar pine, its growth, range, and uses in the form of lumber, and is of interest to foresters and wood users generally.

feet, about equally divided between private and Government ownership. No reliable figures are available for Lower California, but the amount there is known to be small. Within California the best available estimates indicate a stand of 39 billion feet, board measure, about 24 billion on private lands and the remainder in Government ownership within the National Forests. Of the three most valuable widely distributed conifers within the State of California—redwood, yellow pine, and sugar pine—though the sugar pine ranks third in volume of stand, it is undoubtedly first in value of product.

GEOGRAPHICAL AND COMMERCIAL RANGE.

The geographical range of sugar pine extends from the valley of the Santiam River, in the Cascade Range, in Marion County, Oreg., through the Sierra and Coast Ranges of California to Mount San Pedro, in the peninsula of Lower California (Pl. I). Commercially, however, the species is of importance only from Douglas County, Oreg., to Kern County in the California Sierras, and Glenn County in the California Coast Range. The largest trees and heaviest stands within this area are found from Tulare to Eldorado Counties, Cal., along the west slope of the Sierras. Nearly three-fourths of the total stand is found in the Sierra Nevadas of California and the bulk of the remainder within that portion of the Coast Range which lies north of San Francisco. Over one-half of the total is distributed throughout the central Sierra region. It is seldom found in commercial stands on the east side of this range south of Plumas County.

ALTITUDE AND CLIMATE.

The altitudinal range of merchantable stands of sugar pine extends from 3,000 to 6,000 feet in the northern Sierras and from 5,000 to 9,000 in the southern Sierras, the southern coast range, and the Sierra Madres. A few trees have been reported in the redwoods near Cazadero, Sonoma County, Cal., at an elevation as low as 600 feet. The extreme upper limit of the botanical range occurs on Mount San Pedro, in Lower California, where the species has been reported at 11,000 feet. All gradations between these altitudes occur as the latitude changes.

In the sugar-pine belt the summers are hot and dry and the winters moderately cold. Most of the stands are found between the annual isotherms 44° and 60° F. Sugar pine occurs, however, in northern California, where the mean annual temperature is as low as 40°, and in the southern part of the State, where it is as high as 70° F. It endures average minimum monthly temperatures of 20° and average maximum monthly temperatures of 97° F.

Sugar pine is quite dependent upon atmospheric moisture. This characteristic probably accounts, in large measure, for its limited occurrence and poor form on the eastern slope of the Sierra Nevada. The best commercial forests occur where there is an annual precipitation of 40 inches or more, although the species is found between precipitation limits of from 20 to 80 inches. Where the rainfall is below 30 inches, however, the trees are scattered and scrubby in form. The average snowfall in the sugar-pine belt is about 8 feet, with a range of from 3 to 20 feet.

HABIT AND ROOT SYSTEM.

Mature sugar pines have a striking individuality which enables one to indentify them at considerable distances. They generally rise above associated species and send out long, straight branches at right angles to the main stem.

The bole of sugar pine is sturdy, straight, and symmetrical. The taper is quite marked in young trees, but decreases from the fiftieth year until at maturity the trunk is well rounded out and the taper is very slight, except in the stump section. The tops of very old trees are often broken or flat, and the branches are irregular and have the appearance of being sparsely clothed with leaves. Young trees are symmetrical and branch regularly.

Seedlings have a well-developed taproot. This does not keep pace with the general development of the tree, however, and in later years the lateral root system is far more important, sometimes spreading over a radius of 40 feet and rendering the tree very resistant to wind.

BARK, LEAVES, FLOWERS, AND SEED.

The rich purple-brown or cinnamon-red bark of this tree is a distinguishing characteristic. In trees of above middle age it is deeply and irregularly divided into long, thick, platelike ridges. The bark of young trees is thin, quite smooth, and of a grayish color.

The foliage is dark green and composed of rigid needles from 2½ to 4 inches in length, occurring in clusters of 5, except on seedlings, which bear clusters of 12 to 15 seed leaves.

During the spring flowering season the eye is attracted by the conspicuous light-yellow male flowers, oblong in shape, and from ½ to 1 inch in length. The female flowers are of a less attractive pale green color, borne terminally on the branches in groups of two or more.

The cones of sugar pine are unique and serve to identify the species absolutely, mainly because of their great length, which averages from 13 to 18 inches and not uncommonly reaches 23 inches. They mature in late August of the second year, and are then from 2½ to 3½ inches in diameter when closed, with blunt scales, slightly thickened at the tip. They are suspended on stalks at the very tips of the long branches, and when filled with their plump, blackish-brown seeds, from one-quarter to one-half inch in length, their weight imparts a graceful downward sweep to the limb. Even in this position they can not escape the squirrels that depend on the rich-flavored seed for a winter food supply and cut large numbers before maturity.

SIZE AND LONGEVITY.

Sugar pine attains a greater size than yellow pine, white fir, incense cedar, or any of its associates, except the huge Sequoias of the Sierras, which tower far above it in the scattered localities where the two species occur together. Its average maximum height is 175 feet and the corresponding diameter 4½ feet. The maximum height reached is 240 feet and the maximum diameter 11 feet, measured outside the bark at 4½ feet above the ground. The average number of logs per thousand feet board measure, ascertained from sales of National Forest stumpage, varies from 4 in unfavorable situations to 1.5 in the best localities. This species attains an age of 500 years, but rarely more than that.

SUSCEPTIBILITY TO INJURY AND DISEASE.

Various injuries tend to shorten the life of sugar pine, but none result in the immediate death of a high percentage of mature stands except those caused by destructive insects.

FIRE.

Repeated fires cause butt scars or "cat faces," and thus weaken the tree mechanically, retard growth, and bring about conditions favorable to disease. Such scars also decrease the value of butt logs. Seedlings, saplings, and poles are destroyed in large numbers, but very few trees over 12 inches in diameter at breast height are killed, except on steep slopes during very high winds.

LIGHTNING, WIND, FROST, AND SNOW.

Sugar pine undoubtedly is injured more frequently by lightning than its associated species, yellow pine, fir, and incense cedar, because of its greater height and occurrence at relatively high elevations, where such storms are common; but because of the brief season during which lightning storms are prevalent, and their local character, the aggregate amount of damage wrought is not serious. Insects almost invariably attack lightning-damaged trees and complete the destruction, when the wound in itself would not prove fatal.

The strong, widespreading, lateral root system and the thick, sturdy bole of this tree resist winds of extraordinary velocity. Sometimes weakened trees in exposed situations yield to exceptionally severe storms. Large trees are subject to a mechanical defect known as windshake, the result of stresses in the butt section caused by severe wind in conjunction with low temperature. Circular seams are opened up and the value of the trees for lumber is lowered.

Since extremely low temperatures do not occur very often in the sugar pine belt, frost injuries are infrequent. Sapling and pole stands are occasionally injured by the wet snows of early winter, but sugar pine suffers less than yellow pine.

Breakage caused by lightning, winds, or wet snow is serious, not so much in itself, as because it opens the way to attack by insects. Not infrequently such damage gives rise to epidemic insect infestations.

STOCK, RODENTS, AND BIRDS.

Under regulated grazing the damage to young trees by cattle and horses is almost negligible. Sheep and goats, particularly goats, however, do appreciable damage by tramping down and nipping the leaders of young seedlings and saplings. Such stock should not be close-herded on areas of promising young forest, and should be moved frequently. They should be excluded from cut-over areas until reproduction is well started.

Each year the red or Douglas squirrel and the gray squirrel cut large quantities of cones, often while still unripe, and consume or store the edible seed. Other smaller rodents, as well as quail and jays, relish it also. The gray squirrel is so destructive to the seed of this species as to cast doubt upon the wisdom of according him the protection of the game laws in heavily forested counties. Wood rats and rabbits are destructive in young sugar pine plantations, sometimes cutting back every tree to the surface of the ground.

DISEASES.[1]

Sugar pine is without doubt one of the healthiest of our coniferous trees. Even the younger parts, such as the twigs and needles, are rarely attacked by the ordinary enemies of associated tree species, such as mistletoe (*Razovmofskya cryptopoda*), which frequently causes the formation of heavy witches' brooms and gnarls the branches of the yellow, Jeffrey, and lodgepole pine. A small bluish witches' broom, caused either by a parasitic fungus, or more probably, a mite, and resembling a spiny ball from 1 inch to 20 inches in diameter, is fairly common throughout the Sierra Nevadas. An unidentified species of *Peridermium*, probably *P. harknessii*, is also occasionally found on sugar pine. The damage caused by these diseases is, however, insignificant. The wood-destroying fungi cause more damage, but the loss is rarely more than 3 per cent of the gross board measure content of the stand. The fungi almost invariably attack the heartwood of the older and more valuable trees; therefore, though the number of trees killed is small, the monetary loss through their work is appreciable. *Trametes pini* and *Fomes laricis* are by far the most destructive of the wood-destroying fungi which attack sugar pine. Sporophores of *Fomes pinicola* have

[1] Inquiries regarding diseases of forest trees should be addressed to the Bureau of Plant Industry, U. S. Department of Agriculture.

been found on mature green trees. *Polyporus volvatus* is common on dead trees. The damage done by the former is minor, and that wrought by the latter is of no importance.

INSECTS.[1]

Insects are responsible for the destruction of large quantities of merchantable sugar pine timber. In the northern portion of the tree's range bark beetles of the genus Dendroctonus are very destructive; in the southern portions their work is supplemented by that of the flat-head beetles of the family Buprestidæ. The annual loss of sugar-pine timber from beetles is roughly estimated at not less than one-half of 1 per cent of the merchantable stand. In certain localities epidemics of insects have resulted in the loss of from 5 to 10 per cent.

While the roots, limbs, twigs, foliage, cones, and seed of this tree all have insect enemies a tree is never known to have been destroyed except by those which attack the trunk. The mountain pine beetle (*Dendroctonus monticolæ*, Hopk.) is by far the most serious enemy. The adult beetles bore through the cork bark and deposit their eggs in the living inner bark, which is an important part of the circulatory system of the tree. Upon hatching, the larvæ or grubs completely girdle the tree by consuming the tissues in narrow channels or galleries extending around its circumference. The presence of these beetles in a tree is denoted first by reddish "pitch-tubes" or deposits of resin and wood dust caused by the beetles' entrance and later by the yellowing of the crown when the tree begins to feel the effect of the girdling.

The red turpentine beetle (*Dendroctonus valens* Le Conte) attacks the base and roots of the tree. Generally its work is of a secondary nature, but occasionally, when very numerous, it is the primary cause of death. According to the Bureau of Entomology it is also one of the primary causes of basal fire wounds.[2]

From the Kern River southward a species of flat-head borer (*Melanophila gentilis* Le Conte) causes a considerable loss. The five-spined engraver beetle (*Ips confusus* Le Conte) is occasionally responsible for the killing outright of young sugar pines in the sapling or pole stage of growth and for the dead tops of many more mature trees. Other less important insects do minor damage to various parts of the tree. Among these are a weevil (*Pissodes yosemitei* Hopk.), which injures the bark and young saplings; a saw-fly (*Lophyrus* sp.), which damages the foliage, and the sugar pine cone beetle (*Conophthorus lambertianæ* Hopk.), which attacks the stems of the young cones as well as the cones themselves and causes the latter to fall before maturity, thus preventing the maturing of the seed.

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[1] Inquiries in regard to insects affecting forest trees should be addressed to the Branch of Forest Insects, Bureau of Entomology, U. S. Department of Agriculture.

[2] See pages 153–165 of Bureau of Entomology Bulletin 83, Part I, "Practical information on the scolytid beetles of North American forests. Barkbeetles of the genus Dendroctonus," by A. D. Hopkins.

Since slash from cuttings or natural damage, such as windfall or snowbreak, furnishes excellent breeding ground for destructive insects and materially increases the fire danger, such refuse should be disposed of by fire whenever possible before the spring following the cutting or other occurrence.

These insects are normally kept in check by woodpeckers, certain predaceous and parasitic insects, and certain fungi. When, however, an infestation by the mountain-pine beetle commences to increase rapidly it can be controlled only by peeling the infested portions of the principal groups of affected trees during the fall or early spring before the beetles emerge. It is usually necessary as a precaution against fire to dispose of the resulting slash by burning at a safe time. These control measures, as conducted by the Forest Service, have cost from $2.50 to $5 per tree, according to conditions. For each tree cut in control work it seems evident from statistics that one is saved. Since an average sugar pine tree is worth at least $15 on the stump, the saving is worth making.[1]

SILVICAL REQUIREMENTS.

MOISTURE AND SOIL.

The most essential requisite for the rapid development of sugar pine throughout all stages of its life history, but particularly during the seedling and sapling periods, is moisture in both soil and air. Lacking this, it becomes stunted, malformed, and useless as a timber tree. It is generally found on cool northerly slopes and in ravines where the humidity is highest.

Though sugar pine occurs on a variety of soils, from glacial drift and volcanic ash to deep, loose sands and clays, its maximum development is reached only on comparatively moist, loose, deep sandy loam. Its presence is unusual on hot, dry slopes as well as on poorly drained wet soils. The chemical composition of the soil apparently has but little bearing on its distribution.

The relative soil and moisture requirements of this species are indicated by the following list, in which the more exacting species precede the less exacting:

Soil.	Moisture.
Douglas fir.	Red fir.
White fir.	SUGAR PINE.
Red fir.	Douglas fir.
SUGAR PINE.	White fir.
Incense cedar.	Incense cedar.
Yellow pine.	Yellow pine.
Jeffrey pine.	Jeffrey pine.

[1] For further details regarding control measures, see pages 87–89 of Bureau of Entomology Bulletin 83, Part I.

LIGHT.

Sugar pine demands a very great amount of light, except in early youth, and always just as much light as will not interfere seriously with the moisture conditions. The maintaining of the balance between light and moisture offers the hardest problem the forester has to solve in his attempts to increase the representation of this species in the forest mixture of the future. During the seedling and sapling stages, on account of persistent demands for moisture, sugar pine must have at least partial shade. As it gets older, however, it demands more and more light up to the point where a further addition of light would do harm by decreasing too much the amount of moisture in the soil and air.

The relative demands of the different species for light vary, quite naturally, according to geographical and altitudinal location. It may be worth while, nevertheless, to show how sugar pine and its associates rank in this respect where sugar pine is most flourishing. In the following list the trees are ranked in the order of their ability to endure shade:

Western yew	*Taxus brevifolia.*
California nutmeg	*Tumion californicum.*
Mountain or black hemlock	*Tsuga mertensiana.*
Incense cedar	*Libocedrus decurrens.*
White fir	*Abies concolor.*
SUGAR PINE	*Pinus lambertiana.*
Red fir	*Abies magnifica.*
Douglas fir	*Pseudotsuga taxifolia.*
Western white pine	*Pinus monticola.*
Jeffrey pine	*Pinus jeffreyi.*
Western yellow pine	*Pinus ponderosa.*
Juniper	*Juniperus californica.*
Lodgepole pine	*Pinus contorta.*
Knobcone pine	*Pinus attenuata.*
Digger pine	*Pinus sabiniana.*

REPRODUCTION.

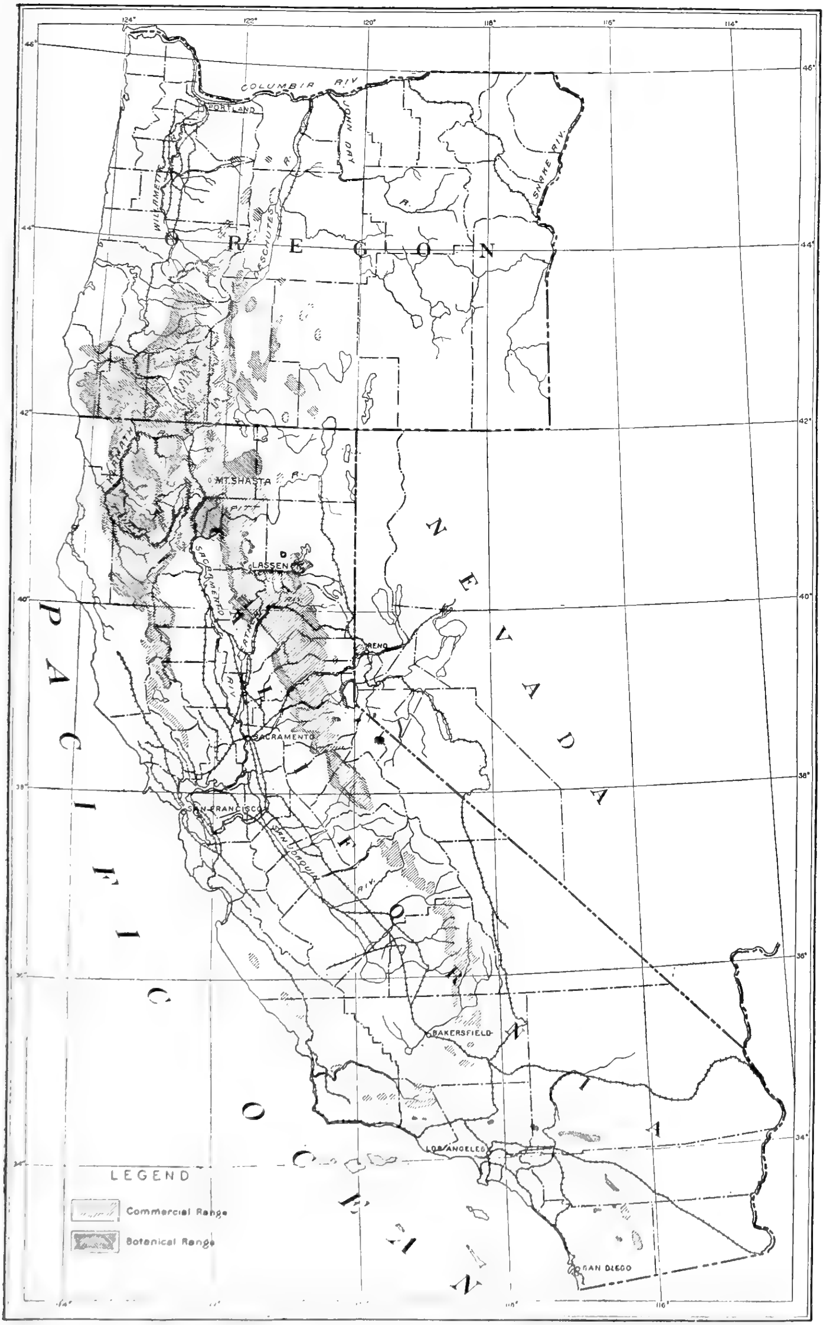
Except under the very best soil, moisture, and shade conditions, there is a noticeable scarcity of sugar-pine reproduction in the present forest, even where this species makes up as much as 25 per cent of the merchantable stand. This scarcity is attributable to the folowing causes:

(1) The seed is very conspicuous and edible. Large quantities are therefore consumed by birds and rodents.

(2) The proportion of the seed that germinates is small.

(3) The moisture requirements for germination are exacting.

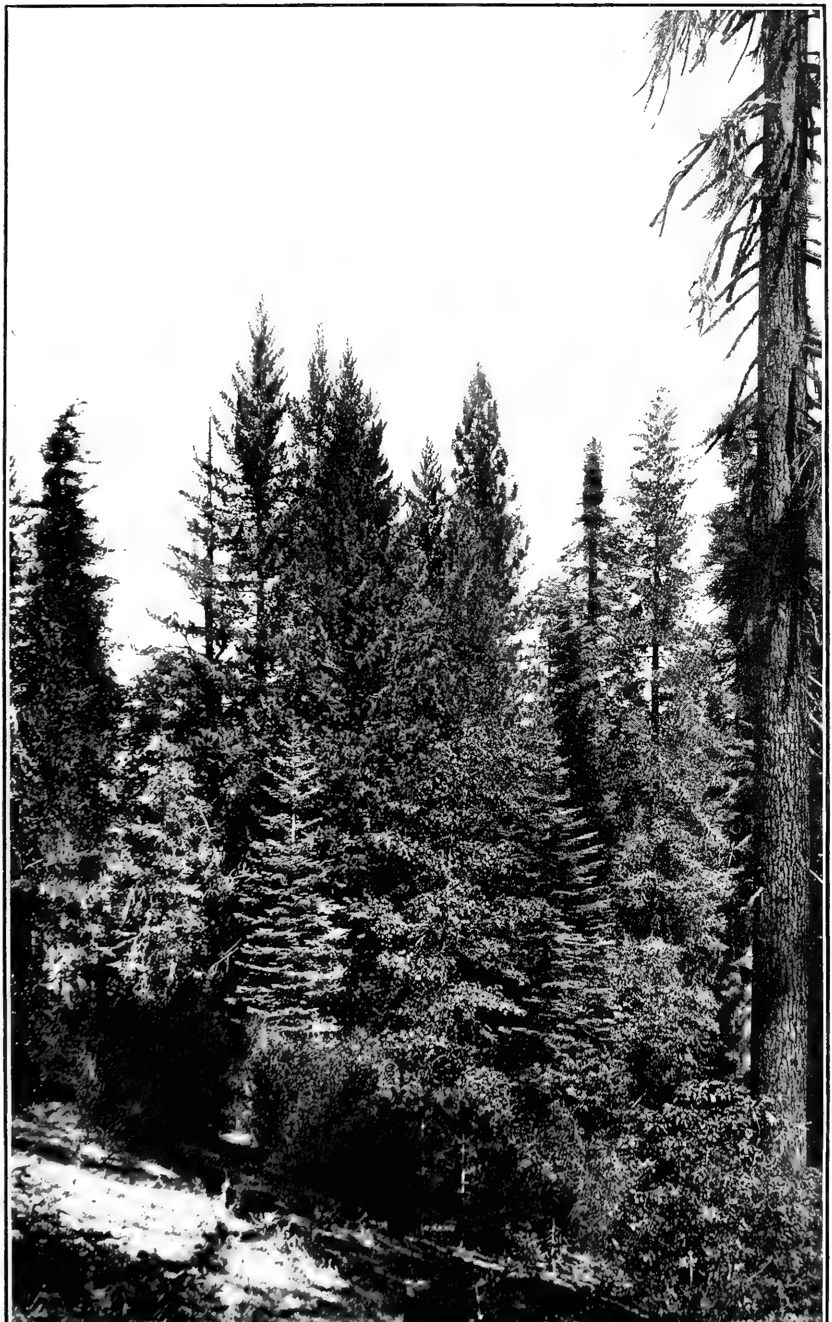
(4) The seedlings are very susceptible to injury from fire, drought, or severe sunlight.



DISTRIBUTION OF SUGAR PINE.

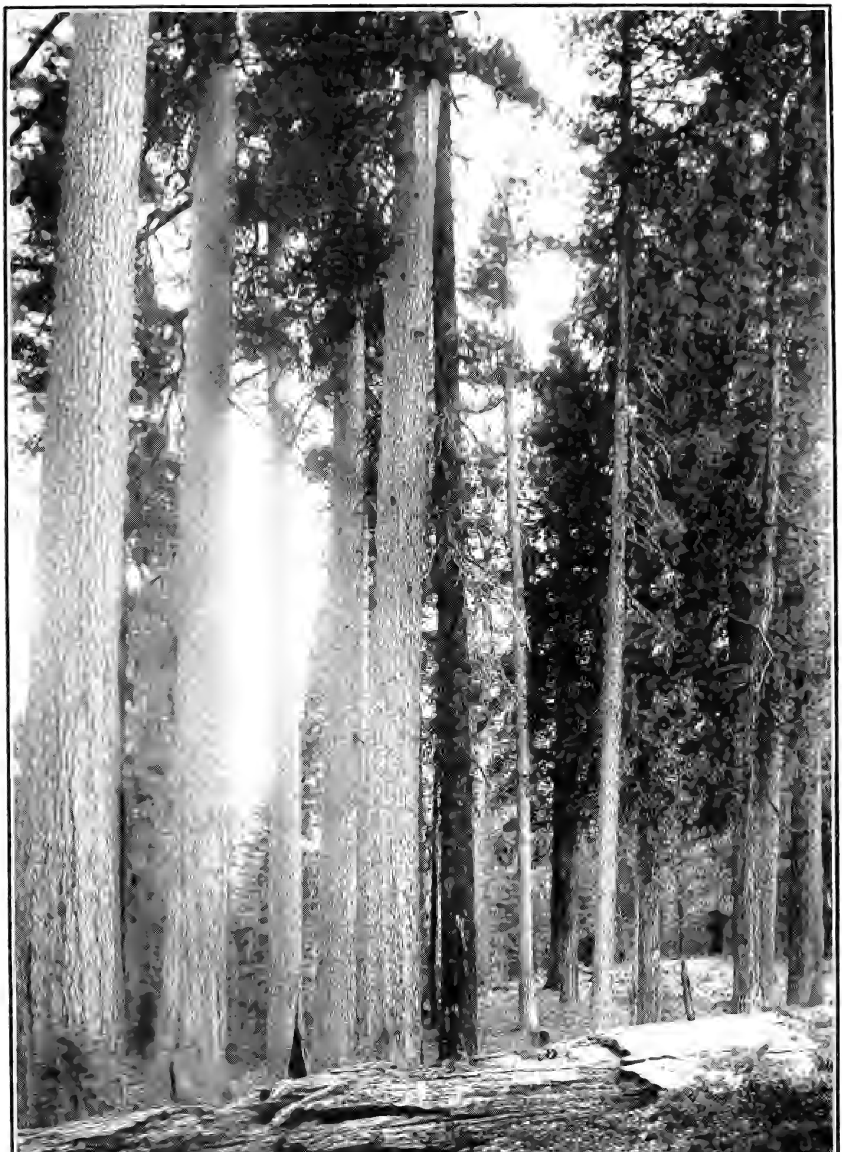
F—1—D5

MATURE SUGAR PINE TREE, SHOWING BOLE, BRANCHING HABIT, AND REPRESENTATIVE CLEAR LENGTH, PLUMAS COUNTY, CAL.



F—2—DB

GROUP OF THRIFTY YOUNG SUGAR PINE, YELLOW PINE, WHITE FIR, AND INCENSE CEDAR SAPLINGS AND POLES, SOUTHERN SIERRA REGION, CALIFORNIA.



F—18252A

CHARACTERISTIC GROUP OF SUGAR PINE TREES IN A GOOD LOCALITY, SUGAR PINE-YELLOW PINE TYPE, SHASTA COUNTY, CAL.

While there is a fair crop of sugar-pine seed each fall in some portion of its range, good seed years throughout occur only at intervals of from three to five years. Cones are occasionally borne by trees from 40 to 50 years old, but the best and most abundant seed is obtained from 125 to 175 year-old trees. The ability to produce seed in large quantities is possessed by huge trees that are long past maturity and deteriorating.

A bushel of cones (about 20, each containing approximately 200 seeds) produces 2 pounds of seed, of which from 20 to 50 per cent will germinate. Germination is peculiarly slow, often continuing throughout two full seasons in seed beds. This makes the species difficult to handle in the nursery.

The seed is disseminated principally by wind, which generally does not transport it over 150 yards, because of its large size and relatively small wings.

On the drier and more exposed situations sugar-pine reproduction can not compete with yellow pine or incense cedar. On humus soils in moist protected spots it succeeds fairly well. Its chief competitor here is the white fir, which has the advantage of bearing abundant light seed, which is not attractive to rodents. The ability of sugar-pine seedlings to endure shade enables them to contend successfully with brush on moist favorable sites. Sugar pine is much more susceptible to injury from ground fires than white fir, yellow pine, or incense cedar seedlings, and the absolute exclusion of fire is essential to the securing of a young stand of this species on cut-over areas.

FOREST TYPES.

Sugar pine frequently occurs in pure stands covering about an acre, but is never found on larger areas without other species in mixture. Yellow pine, incense cedar, white fir, and Douglas fir are its most common associates, followed by red fir and Jeffrey pine at higher elevations. Occasionally it mingles with western white pine, lodgepole pine, yew, whitebark pine, limber pine, knobcone pine, coulter pine, and at low elevations with various species of oak. These combinations, however, are only of botanical interest. Largely as a result of repeated fires, stands of sugar pine are generally rather open and contain considerable underbrush, composed of various species of ceanothus, manzanita, oaks, buckthorns, cherries, serviceberry, and chinquapin.

For descriptive purposes, stands containing sugar pine have been divided into the following cover types, based upon the number of trees of each species that are found in mixture.

SUGAR PINE-YELLOW PINE TYPE.

In the sugar pine-yellow pine type, sugar pine makes up over 15 per cent of the stand, its associates in the order of their commercial importance being yellow pine, white fir, Douglas fir, incense cedar, Jeffrey pine, and bigtree. This type generally occurs at an elevation of from 4,000 to 7,000 feet in the western central Sierra region of California. Sugar pine is at its best in this region and many large pine lumbering operations are located within it. The altitudinal limits of the type vary with change of latitude, being somewhat lower in the northern part of California and higher in the southern. Because of the exacting moisture requirements of sugar pine, the heaviest stands in this type are found in moist draws, or gulches, where the humidity is highest, and on north and east slopes. It is in the gulches that Douglas fir is most prominent. On the hotter, drier slopes, sugar pine is largely replaced by yellow pine and cedar.

SUGAR-PINE FIR TYPE.

The sugar pine-fir type has over 15 per cent sugar pine, Douglas fir and white fir in considerable quantities, and no yellow pine. It occurs in favorable moist, humid situations and is found principally in the northern portion of the Sierra Nevadas and Coast Ranges. This type covers a much smaller area than the sugar pine-yellow pine type and is relatively unimportant. To the south it merges into the yellow pine-sugar pine or fir type.

In addition to these two distinct cover types in which sugar pine is the key tree, it is found less well represented in the yellow pine, Jeffrey pine, fir, and red fir types. In short, wherever the annual precipitation is sufficient to meet its requirements and sufficient light is available, this tree may be found. As moisture conditions become less favorable it seeks sheltered localities, and as they improve it ventures into more exposed situations. The dense shade and fogs of the coast redwood and Douglas fir forests prevent it from becoming an important factor in the heavily forested belt west of the California coast range.

THE WOOD.

APPEARANCE AND STRUCTURE.

In external appearance the wood of sugar pine is strikingly similar to that of eastern white pine (*Pinus strobus*) and western white pine (*Pinus monticola*). The sapwood and heartwood are fairly well defined; the former is white or yellowish white, the latter a very light brown, sometimes tinged with red in old trees which are very resinous.

QUALITY.[1]

Sugar pine is moderately hard and heavy, moderately strong and stiff, poor in shock-resisting ability, moderately coarse but straight-

[1] The paragraphs dealing with markets and manufacture and the uses, quality, weight, strength, durability, and treatment of the wood were prepared by Carl A. Kupfer, forest examiner, Forest Service.

grained, and of smooth, rather fine texture. It is easily worked, takes a nail well without splitting, and when finished has a satiny luster. Among woods showing only slight shrinkage, swelling, and warping due to varying atmospheric conditions, sugar pine ranks with the best. Although resinous, it is comparatively free from noxious elements which impart contaminating flavors and odors.

WEIGHT, STRENGTH, SHRINKAGE, AND HARDNESS.

The following figures on weight, strength, shrinkage, and hardness of sugar pine are largely the result of tests conducted by the Forest Service on material from five representatives trees cut in Madera County, Cal. These tests were made at the Forest Products Laboratory, Madison, Wis., and the results are directly comparable with those obtained for the other commercial woods which have been studied. The test specimens used were small and clear, and for strength determinations were 2 by 2 inches in section. Bending specimens were cut 30 inches long; others were shorter, depending on the kind of test.

TABLE 1.—*Shipping weights, sugar pine lumber, per 1,000 feet board measure.*

2-inch dimension.		1-inch boards.		4-foot lath (per thousand).
Rough.	S1S1E.	Rough.	S1S or S2S.	
Pounds. 2,650	*Pounds.* 2,300	*Pounds.* 2,500	*Pounds.* 2,200	*Pounds.* 450

TABLE 2.—*Average mechanical properties of small, clear, green sticks of sugar pine, western yellow pine, white pine, and Douglas fir.*

Species.	Static bending.			Compression parallel to to grain.	Compression perpendicular to grain.
	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Crushing strength.	Fiber stress at elastic limit.
	Lbs. per sq. in.	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Douglas fir (Pacific Northwest)	4,920	7,795	1,577	3,910	528
Sugar pine (California)	3,330	5,270	966	2,600	353
White pine (Wisconsin)	3,410	5,310	1,073	2,720	314
Western yellow pine (California)	3,180	5,180	1,111	2,420	326

TABLE 3.—*Shrinkage of small, clear pieces of sugar pine, western yellow pine, white pine, and Douglas fir from green to oven-dry condition.*

Species.	In volume.	Radial.	Tangential.
	Per cent.	*Per cent.*	*Per cent.*
Douglas fir (Pacific Northwest)	12.7	5.0	7.8
Sugar pine (California)	8.4	2.9	5.6
White pine (Wisconsin)	7.8	2.2	5.9
Western yellow pine (California)	11.5	4.3	7.3

TABLE 4.—*Hardness of small, clear, green sticks of sugar pine, western yellow pine, white pine, and Douglas fir.*

Species.	Surface.		
	End.	Radial.	Tangential.
	Load required to embed a 0.444-inch steel ball to one-half its diameter.		
	Pounds.	*Pounds.*	*Pounds.*
Douglas fir (Pacific Northwest)	511	457	490
Sugar pine (California)	334	307	342
White pine (Wisconsin)	304	294	299
Western yellow pine (California)	316	306	323

The specific gravity of the dry wood of sugar pine is 0.386. The weight of a cubic foot of oven-dry wood is 24.1 pounds. The weight of white pine (*P. strobus*) is 24.4 and of western yellow pine (*P. ponderosa*) 26.3 pounds. The green weights per cubic foot for the three species are: Sugar pine, 50.2 pounds; white pine, 39.5 pounds; western yellow pine, 48 to 53.1 pounds.

The shipping weights for sugar pine lumber of different sizes, accepted by manufacturers, are shown in Table 1. Table 2 shows the strength, Table 3 the shrinkage, and Table 4 the hardness of sugar pine and several other species.

DURABILITY.

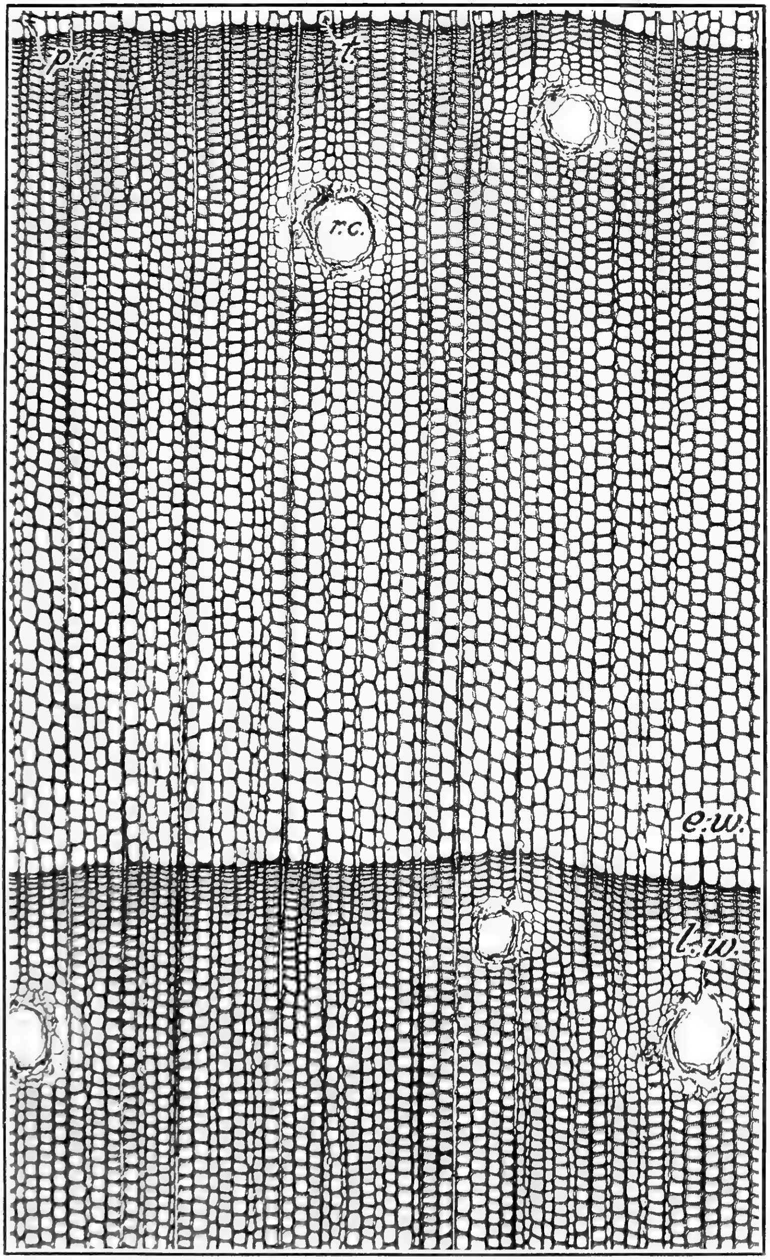
Early settlers found sugar pine more durable than the commoner western yellow pine and used a great deal in fence construction and building. In contact with the ground it lasts longer than most of the common Sierra species, but is not so durable as incense cedar or juniper. In the air, even where exposed to all kinds of weather, it shows great lasting properties.

TREATMENT.

So far as is known, no attempt has been made to increase the life of sugar pine by preservative treatment. Its value for other purposes is so great that very little of it is used in contact with the ground. Theoretically, the sapwood should receive preservatives very readily, but the heartwood, like that of white pine, is so close-grained as to resist absorption and penetration under ordinary methods of treatment. Applications of paint, oil, varnish, or shellac, or boiling in oils or paraffin, would doubtless increase its life by preventing the absorption of water.

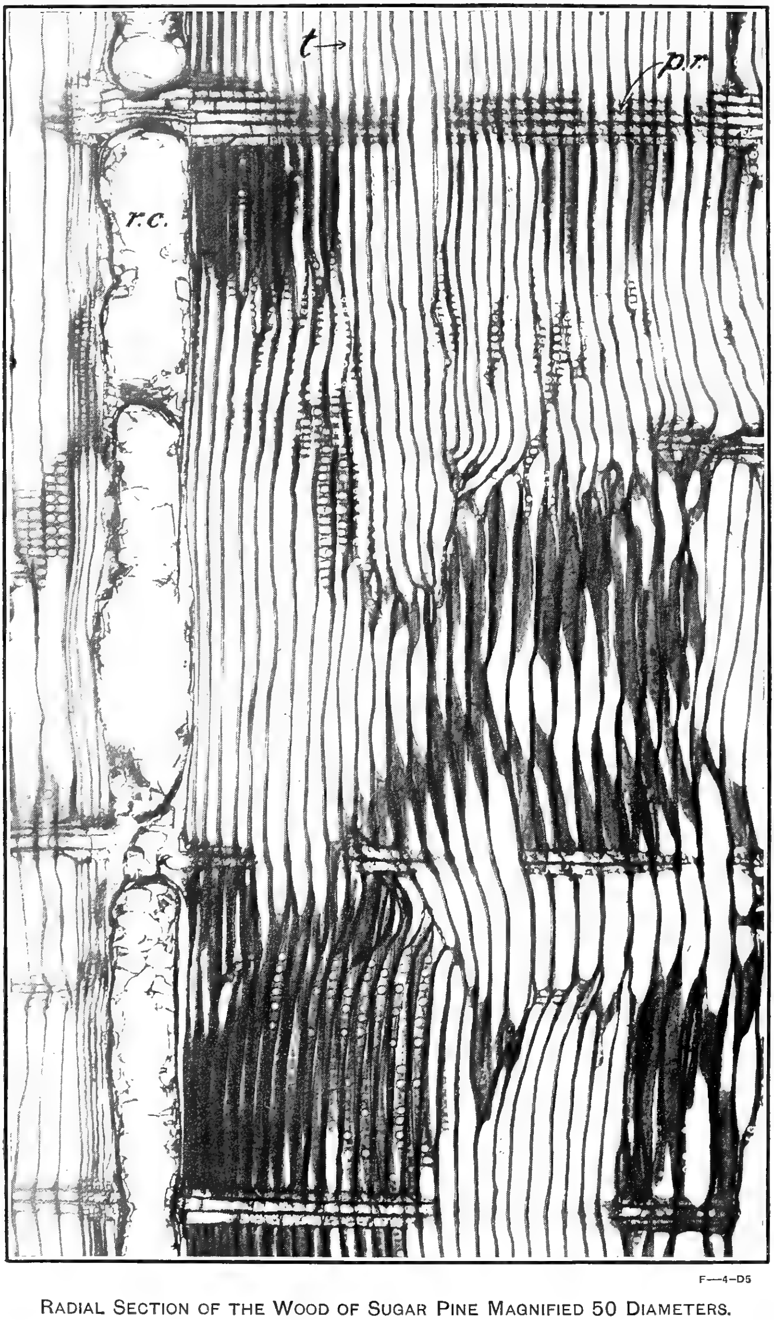
LOGGING.

The process of logging sugar pine in a typical California operation consists of the following steps: Felling, bucking, yarding, chuting or "roading," loading, hauling to mill.



TRANSVERSE SECTION OF THE WOOD OF SUGAR PINE MAGNIFIED 50 DIAMETERS.

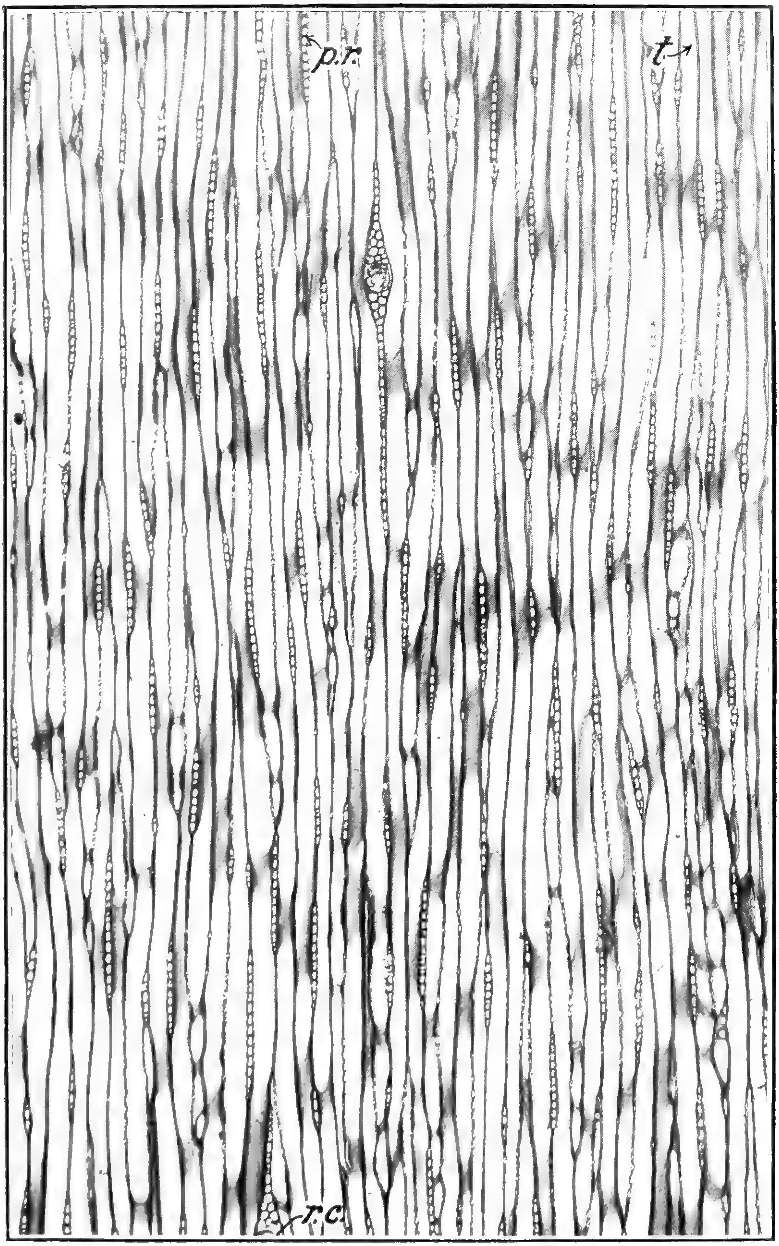
e. w., Early wood; *l. w.*, late wood; *t.*, tracheids; *p. r.*, pith rays; *r. c.*, resin canal.



F—4—D5

RADIAL SECTION OF THE WOOD OF SUGAR PINE MAGNIFIED 50 DIAMETERS.

t., Tracheids; *p. r.*, pith rays; *r. c.*, resin canal.



TANGENTIAL SECTION OF THE WOOD OF SUGAR PINE MAGNIFIED 50 DIAMETERS.

t., Tracheids; *p. r.*, pith rays; *r. c.*, resin canal in pith ray.

The felling crew is generally made up of an undercutter, who decides which way the tree shall fall and notches it with an axe on that side, and two "fallers," who cut the tree down with a cross-cut saw. Such a crew usually fell from 55,000 to 60,000 feet per day. They are followed by the marker, who divides the tree into the proper log lengths, and the buckers, who cut it into logs. Working singly with cross-cut saws, the buckers average 9,000 to 10,000 feet daily.

The next step, yarding, consists in transporting the logs from the woods to the chutes or railroad landings. This is accomplished generally by means of steam donkey engines called "yarders," which operate strong wire cables reeled on drums. The largest machines can carry sufficient cable to bring in logs 2,000 feet away; 1,200 feet is an average pull, however. From 10 to 13 men are required in a yarding crew for handling from 25,000 to 40,000 feet of logs per day. Wherever possible, logging railroads are used and the yarding engines are located along these roads. Sometimes, however, when the logs reach the yarder they are placed in V-shaped log chutes and pulled to the mill or railroad by another usually larger, donkey engine known as the chute donkey, roader, or bull donkey.

At the mill the logs are generally placed in a pond for storage. From here they can be readily pulled into the mill for sawing.

The average cost per 1,000 feet of logging sugar pine and yellow pine is about $5.30, itemized as follows:

Felling and bucking	$0.65	Chute construction	$0.15
Yarding	1.80	Railroad	.50
Chuting (54 per cent of cut)	.35	Depreciation	.35
Loading	.25		5.30
Railroad haul	1.00		
Supervision	.25		

In the sugar-pine region various methods of logging are used. Small-mill operators can not make the heavy investments necessary for donkey engines, and they commonly yard logs to chutes by means of six-horse or eight-horse teams. The logs are hauled in the chutes in trains of 8 or 10 by similar teams. These horse chutes usually end at the mill. Other small outfits deliver the logs at the mill by means of eight-horse trucks, which are loaded by horses at landings in the woods. In the northern part of California many localities are so smooth that large operators find it an economy to yard logs by means of horses and overhead big wheels.

MILLING.

Two main types of mills are used, those in which circular saws do the cutting, and the larger, more modern mills, which employ band saws. Rotary mills usually saw lumber for the local market. While such mills require a smaller investment than band mills, their output is less, the cost of operation is higher, and the waste is greater. The usual daily output of circular mills varies from 20,000 to 40,000 feet, while single band saws cut about 60,000 feet in a 10-hour shift. The double-band type is usually installed now by large operators. Such a mill running night and day, a practice frequently followed during good market conditions, manufactures from 225,000 to 250,000 feet of lumber each day, or from 40,000,000 to 50,000,000 feet each season.

The following cost items give a correct general idea of the expense of manufacturing sugar-pine lumber from the time logs reach the pond up to and including the loading of the finished lumber on cars for shipment.

Cost per 1,000 board feet.

Unloading logs in pond	$0.07
Milling	1.50
Maintenance	.50
Distribution and yard handling	.33
Piling	.40
Surfacing a part of stock and loading on cars	.90
	3.70

Sugar pine is cut in the following stock sizes: 1″, $1\frac{1}{4}$″, $1\frac{1}{2}$″, 2″, $2\frac{1}{2}$″, 3″, and 4″ in grades Nos. 1, 2, and 3 clear and Nos. 1 and 2 shop. Dimension stock, graded Nos. 1, 2, and 3 common, is cut 1″ and 2″, while box, which uses up nearly the entire output of common, is cut 1″ and $1\frac{1}{2}$″. All grades above common are cut to surface, on two sides, full $\frac{7}{8}$″, $1\frac{7}{16}$″ $1\frac{3}{16}$″, $1\frac{7}{8}$″, $2\frac{3}{16}$″, $2\frac{7}{8}$″, and $3\frac{7}{8}$″. Slabs and other "waste" sometimes are used in the manufacture of 4-foot lath. Much of the sugar-pine lumber now being supplied to the markets east of the Sierras is in the form of shop lumber for general mill-work. Siding, ceiling, etc., are manufactured only incidentally to fill special orders, and can not be considered standard products of sugar-pine mills.

CUT.

Sugar pine was not exploited extensively until 1895, and no attempt to market it as a separate species was made until 1901. Exact figures showing the amount cut up to 1907 are not available, but, as nearly as can be ascertained, this amount ranged from 30,000,000 feet in 1902 to 90,000,000 feet in 1907. The mills cutting sugar pine and other species produced approximately 500,000,000 feet board measure, of all species, annually from 1909 to 1913. Sugar pine formed 22 per cent of this amount, or 110,000,000 feet. The cut in 1908 was somewhat less on account of the industrial depression. In 1913 the cut was close to 120,000,000 feet.

Probably a billion feet of sugar pine has been cut since 1901, or a little over 2 per cent of the total stand. The disturbances in the lumber market attendant upon the European war have probably decreased this scale of production temporarily. Large holders of pine timber are, however, beginning to feel the pressure of interest charges, taxes, and other items of expense connected with carrying stumpage. Operations have recently started on a large scale on two such holdings, and there are indications that several more will follow within the next 5 years should market conditions improve with the closing of the war in Europe. The carrying charges on National Forest stumpage are borne by the United States, and a constantly increasing number of lumbermen are operating in Government timber. It is predicted that the annual cut of California pine will reach 650,000,000 feet by 1920. Of this amount 150,000,000 should be sugar pine.

Table 5 gives the number and type of the principal mills at present producing sugar-pine lumber, together with their average and total annual output of this species.

TABLE 5.

	Type of mill.			
	Double band.	Single band.	Circular.	Total.
Number of mills	10	8	15	33
Average annual output, feet, b. m.	8,008,000	2,500,000	704,000	11,212,000
Total annual output, feet, b. m.	80,080,000	20,002,000	10,561,000	110,643,000

GRADE PRODUCT OF SUGAR-PINE LOGS.

The average quality of sugar-pine timber is fairly well indicated by the results of a mill tally of 855 logs made during the summer of 1914 at about the middle of the range of this species from north to south. Farther south the quality is better, and farther north, poorer. The logs are divided into three grades: Grade I, or clear logs; Grade II, or shop logs; and Grade III, or rough, common logs. Both sound and defective logs were tallied. Grade I logs made up 22.7 per cent of the net log scale; Grade II, 42.8 per cent, and Grade III, 34.5 per cent.

Including both sound and defective logs, the quality of lumber within each log grade, by actual tally, is shown in Table 6.

TABLE 6.—*Lumber grade product of sugar pine within log grades.*

Grade of log.	1 and 2 clear.	3 clear.	C select.	Australian.	1 shop.	2 shop.	3 shop.	1 and 2 common.	3 common.	Box.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Grade I	33.6	9.3	0.2	0.5	19.3	11.0	2.6	1.0		8.5
Grade II	4.2	2.6	.1	.1	15.9	22.3	7.7	37.9	0.4	8.8
Grade III	.9	.4			2.7	6.8	6.6	63.2		19.4
All grades	9.4	3.3	.1	.2	11.9	14.2	6.2	41.9	.2	12.5

The proportion of each of the principal lumber grades produced from diameter classes of sound logs is given in Table 7. The diameter classes are based upon the small-end diameters of logs and are inclusive.

TABLE 7.—*Lumber grade product of sugar pine by log grades and log diameter classes.*

LOG GRADE I.

Diameter class logs.	1 and 2 clear.	3 clear.	1 shop.	2 shop.	3 shop.	1 and 2 common.	Box.
	Per ct.	*Per ct.*	*Per ct.*	*Per c*	*Per c*	*Per ct.*	*Per ct.*
25 to 28 inches	21	8	19	10	2	35	5
29 to 32 inches	23	8	20	11	2	31	5
33 to 36 inches	25	9	21	11	3	25	6
37 to 40 inches	27	10	22	11	3	21	6
41 to 44 inches	30	10	22	12	3	16	7
GRADE II.							
21 to 24 inches	3	2	10	18	6	57	4
25 to 28 inches	3	2	11	23	6	50	5
29 to 32 inches	3	2	13	25	6	44	6
33 to 36 inches	4	2	17	26	6	38	7
37 to 40 inches	6	4	20	24	6	33	7
41 to 44 inches	7	5	22	21	7	30	8
GRADE III.							
9 to 12 inches						86	14
13 to 16 inches				0.5	0.5	84	15
17 to 20 inches	0.1		1	2	3	80	14.9
21 to 24 inches	0.2	0.1	2	7	8	68	14.7
25 to 28 inches	0.3	0.1	3	12	13	58	13.6
29 to 32 inches	0.4	0.2	4	15	17	50	13.4
33 to 36 inches	0.4	0.2	6	19	21	41	12.4

The same study gave figures on the overrun of the lumber tally over the log scale (Table 8). The mill was an efficient single band with standard equipment. The sawing practice was normal for the region, except that railroad ties were sawed from many of the top logs, which gave too high an overrun for Grade III logs.

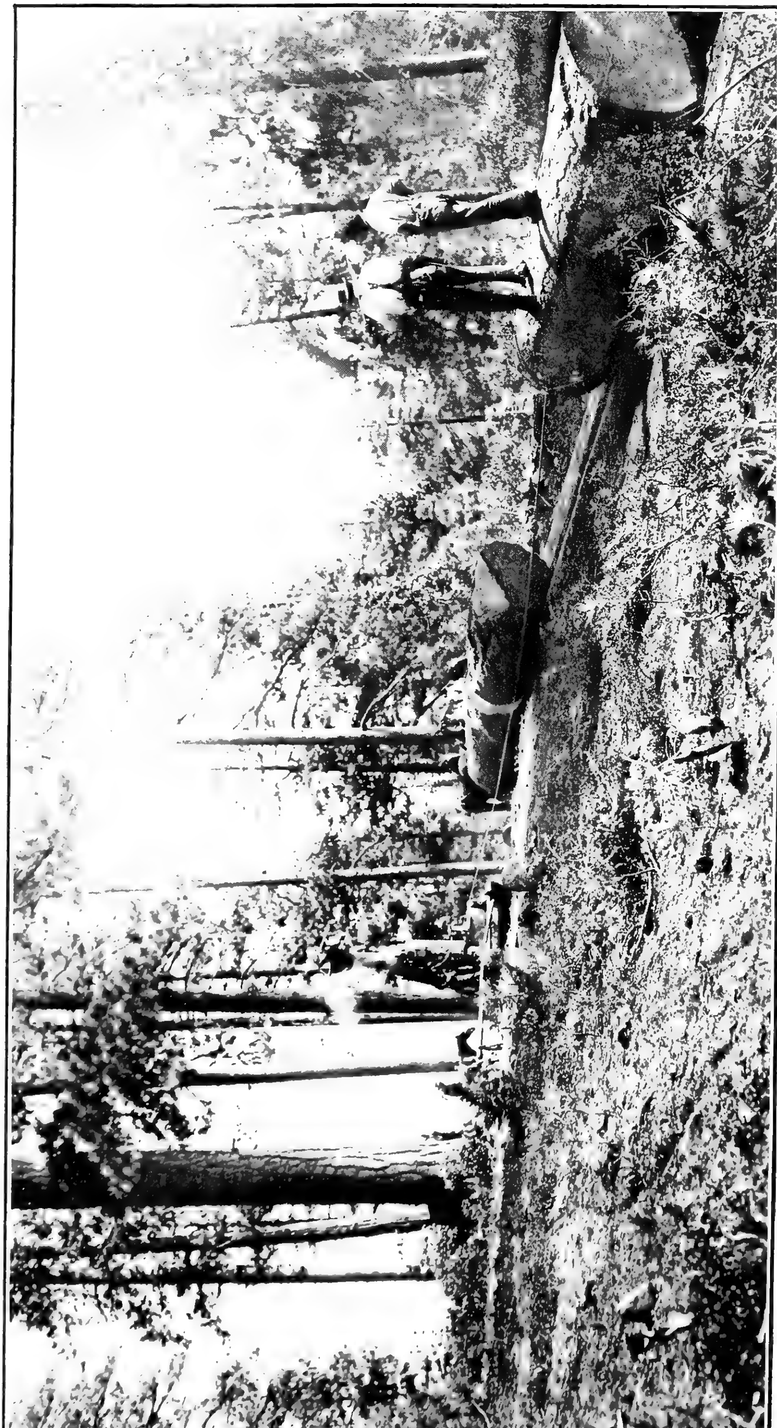
TABLE 8.—*Overrun by log grades and log quality.*

	Sound logs.	Defective logs.	Sound and defective logs.
	Per cent of the log scale.		
Grade I	3.0	2.1	2.6
Grade II	6.3	4.6	5.9
Grade III	11.6	8.9	11.1
Total	7.8	4.6	7.0

VALUES AND GRADES OF LUMBER.

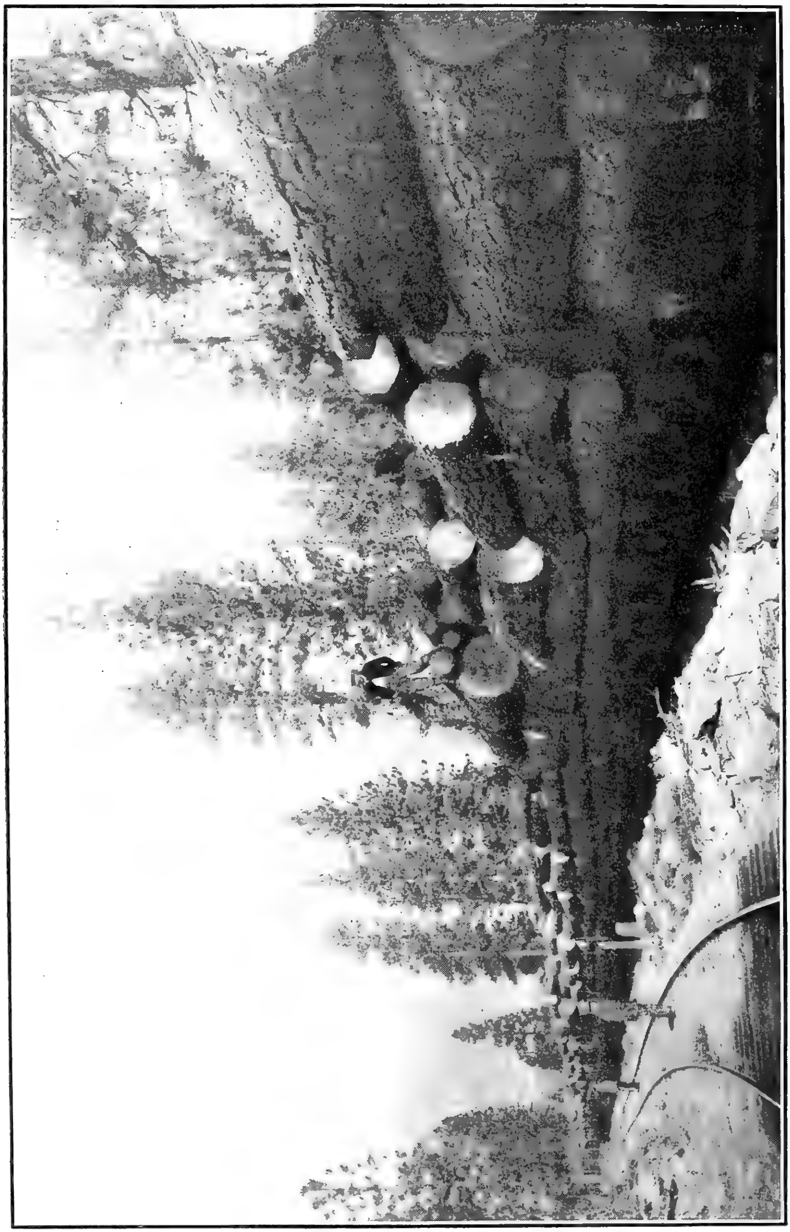
The value and amount of the higher grades of lumber obtained from a species measure its intrinsic commercial worth.

Sugar pine logs yield a higher percentage of wide, clear, high-grade lumber than yellow pine. This material commands a high price for special uses in the trades, which accounts for the lumberman's



F—95302

CHUTE LOGGING WITH A DONKEY ENGINE, PLUMAS COUNTY, CAL.



F—30927

TRAINLOAD OF PINE LOGS, SISKIYOU COUNTY, CAL.

decided preference for sugar pine timber. The choice material is derived from large, overmature trees. The smaller trees are on a par with yellow pine in value of product, and at the time of a second cutting the value of these two species will undoubtedly be nearly identical.

Table 9 shows the average percentage of the various grades produced from sugar pine and yellow pine in the best representative Sierra Nevada stands. In the very best stands sugar pine cuts out as high as 50 per cent upper-grade lumber (No. 2 shop and better).

TABLE 9.—*Average percentage of the various grades produced from sugar pine and yellow pine.*

Grade.[1]	Species.		Grade.[1]	Species.	
	Sugar pine.	Yellow pine.		Sugar pine.	Yellow pine.
No. 1 and clear	13.2	10.0	No. 3 shop	5.0	6.0
No. 3 clear	6.6	3.6	No. 1 and 2 common	22.0	25.0
C select		3.6	Box	23.0	27.0
No. 1 shop	11.0	9.0	No. 3 common	6.0	5.0
No. 2 shop	13.2	10.8			
Total uppers	44.0	37.0	Total lowers	56.0	63.0

[1] Sugar and yellow pine are graded under rules established by the California Sugar and White Pine Co., of San Francisco, Cal. (See Appendix, p. 40.)

Although market prices fluctuate considerably from year to year, they indicate comparative values. There was a strong rising market for California sugar pine from 1903 to 1907. The financial depression of 1907 produced a decided slump, which was followed by a partial recovery in 1909. From 1909 to 1912 prices were fairly constant, with a slight tendency to increase. In 1914 the general business depression and European war were severely felt in the pine market.

Table 10 shows concretely the general increase in the price of upper grades and a comparison between 1905 and 1912 prices.

TABLE 10.—*Net selling price of sugar and yellow pine lumber by grades, f. o. b. mill*

Grades.	Prices per 1,000 feet.		
	1905	1912	
	Sugar pine.	Sugar pine.	Yellow pine.
Nos. 1 and 2 clear	$43.00-$46.00	$50.00-$57.00	$37.75-$42.50
No. 3 clear	33.00- 38.00	38.00- 40.00	32.00- 34.00
C select		38.00- 40.00	31.00- 33.00
No. 1 shop	22.00- 28.00	30.70- 31.30	24.00- 26.50
No. 2 shop	15.00- 18.00	20.45- 22.00	15.50- 20.00
No. 3 shop		13.25- 15.00	13.00- 15.00
Nos. 1 and 2 common		14.75- 18.00	14.00- 18.00
Box		12.50- 13.50	12.00- 13.50
No 3 common		10.00- 12.00	3.10- 11.40

The "mill-run" value, which is the average of all prices obtained for the various grades manufactured, varies with the location of the mill and the quality of the timber. The greater the proportion of the lower grades produced, the lower is the average mill-run price. In appraisals of National Forest stumpage, the average mill-run prices of sugar pine shown in Table 11 were ascertained upon the basis of selling prices current during 1912.

TABLE 11.—*Mill-run values of sugar pine lumber.*

[Price per 1,000 feet.]

Locality.	Species.		Locality.	Species.	
	Sugar pine.	Yellow pine.		Sugar pine.	Yellow pine.
Siskiyou County	$21.00	$19.00	Plumas County	$23.00	$19.00
Upper Sacramento	21.00	19.00	Central San Joaquin	24.00	20.00
Lower Sacramento	24.10	19.80	Southern San Joaquin	23.45	19.65

DEPRECIATION OF SUGAR-PINE LUMBER DURING AIR SEASONING.

In the summer of 1914, the Forest Service carried on a study to determine the depreciation in grade of pine lumber during air seasoning. Depreciation during seasoning by this method is caused by checks, blue stain, brown stain, warping, splitting, and breakage in handling. The heaviest depreciation occurs in high-grade lumber (No. 2 shop and better). The amount of loss is determined largely by climatic conditions, method of piling, location of pile, length of ime in pile, and characteristics of species.

At lumber yards in the hot valley regions of California brown stain seems to cause one-third of the depreciation in grade.

Table 12 shows the percentage of the total loss in grade in rough sugar-pine lumber, No. 2 shop and better, which resulted from blue and brown stain during air seasoning at such a yard.

TABLE 12.—*Percentage of total loss in grade in rough sugar-pine lumber.*

Defect.	Thickness in quarter inches.							Total.
	4/4	5/4	6/4	8/4	10/4	12/4	16/4	
	Percentage of loss.							
Blue stain	19.67	3.94	3.35	3.56				5.09
Brown stain	10.70	4.33	44.29	39.33	2.01			35.87
Blue and brown	4.44	5.46	4.63	6.06				5.38
Total								46.34

In cooler mountain yards the loss from blue stain is much greater than that indicated in this table, and the loss from brown stain much less. Brown stain develops rapidly in kiln drying, and for this reason but comparatively little sugar-pine lumber is artificially seasoned. Heavy thick boards cut from the sapwood are especially subject to brown stain, while heartwood boards seldom stain except under the "stickers."

Table 13 gives the results secured from piles at a representative mill in the central Sierras, elevation 2,500 feet. These results should be considered simply as illustrations of what has occurred under certain specific conditions. The study has not yet progressed far enough to allow of general conclusions.

At this mill all sugar pine is air seasoned. The No. 3 shop and better is cut principally 6/4 in thickness, although 4/4, 5/4, 8/4, and 10/4 material is manufactured. Depreciation increases with the thickness of the lumber.

The piles of No. 3 shop and better were put up with three 2 by 4 by 16 inch rough-dry white-fir stickers and three 8-inch chimneys. The pile foundations had a slope of 1 inch to the foot. Piles were roofed and sun covers were used on highest grade material.

TABLE 13.—*Depreciation in various grades of sugar-pine lumber during air seasoning at a mill in the central Sierras, California.*

Original grade and thickness.	Length of time in pile.	Total contents pile.	Amount lowered in grade.	Value loss.
		Feet b. m.	*Feet b. m.*	
1, 2, and 3 clear—8/4	Aug. 5, 1914, to Oct. 14, 1914	10,244	2,086	$3.71
1, 2, and 3 clear—6/4	July 14, 1914, to Oct. 14, 1914	4,371	75	.37
No. 1 shop—6/4	May 31, 1914, to Oct. 13, 1914	5,334	51	.10
No. 1 shop—6/4	May 1, 1914, to Oct. 10, 1914	4,582	7	....
No. 1 shop—8/4	Aug. 20, 1914, to Oct. 10, 1914	27,606	810	.30
No. 2 shop—6/4	July 24, 1913, to June 13, 1914	4,842	260	.42
No. 2 shop—6/4	Oct. 30, 1913, to Oct. 1, 1914	16,585	207	.10
No. 2 shop—6/4	Apr. 28, 1914, to Oct. 1, 1914	6,733	....	....

The summer depreciation at this mill in connection with air seasoning of sugar pine appears to be about $1.90 per 1,000 feet for Nos. 1, 2, and 3 clear, 15 cents for No. 1 shop, and 12 cents for No. 2 shop. In addition to this, it is estimated that about 1 per cent of the material depreciates one grade during the winter.

Upon the basis of this study, the following suggestions are offered for decreasing loss through depreciation in grade during air seasoning.

(1) Cut thick stock (8/4 and thicker No. 2 shop and better) early in the season so as to allow time for drying.

(2) Clear away vegetation around piles.

(3) Keep rear pile foundations far enough off ground to allow of good air circulation.

(4) Provide a roof with 4-foot extensions front and rear for piles of high-grade pine left in yard over winter.

(5) Provide sun covers during summer for piles of high-grade material.

(6) Provide shed capacity for as much dry lumber as possible to be held over winter.

(7) Whenever possible, take down lumber as soon as it is dry.

(8) Pile each length of lumber separately.

(9) Surface stickers when blackened by stain.

(10) Whenever possible, saw 8/4 and thicker pine stock either all sap or all heart.

MARKETS.

Sugar pine is being called upon more and more each year to take the place of eastern white pine (*P. strobus*), which for the past two centuries has represented the standard of excellence, not only in America, but in many foreign markets as well. The development of new markets in recent years has made possible the introduction of sugar pine in South America, the islands of the Pacific, and the Orient, and, wherever introduced, it is meeting with the same general success which has characterized its entrance into the markets once wholly supplied by white pine. In large dimensions it has already largely supplanted the latter. Its uniformly high quality is gradually gaining for it well-merited recognition in many specialized industries. The leading manufacturing industries along the Pacific coast, from Seattle to Los Angeles, are dependent largely upon sugar pine for the high-grade products for which white pine has been essential in other parts of the United States. The wood-using industries of the coast consume nearly 60,000,000 feet annually, the manufacturing plants of California alone working up 35,000,000 feet (exclusive of bridge construction, sluicing, dimension stock, and general building material). Fifteen million feet are shipped annually into the territory lying between the Rocky Mountains and the Atlantic seaboard, and 10,000,000 feet go to foreign ports.

USES.

In 1908 the amount of white pine manufactured was 33 times the amount of sugar pine; in 1911 the ratio was reduced to 27 to 1, primarily because of the decrease in the supply of white pine and in a lesser degree because of an increase in the cut of sugar pine. In 1911 sugar pine ranked twenty-fourth in the United States in the amount of sound lumber produced.

TABLE 14.—*Amount of sugar-pine lumber used in various California industries in 1910.*

Industry.	Feet used, b. m.	Per cent of total.	Industry.	Feet used, b. m.	Per cent of total.
Boxes and packing	20,536,000	58.763	Sash, doors, blinds, general millwork	11,930,303	34.140
Brushes	3,440	.010	Ship and boat building	75,000	.220
Elevators	15,000	.043	Tanks	10,750	.031
Fixtures	150,000	.430	Trunks and valises	11,000	.031
Frames and molding	2,730	.008	Vehicle parts	1,000	.003
Furniture	364,410	1.043	Wood carvings	3,000	.008
Musical instruments	4,700	.014	Woodenware and novelties	418,563	1.200
Instruments, professional and scientific	500	.001	Miscellaneous	40,000	.120
Machine parts	4,000	.012			
Patterns	59,350	.113	Total	34,946,956	99.9
Planing-mill products	1,317,060	3.770			

Table 14 shows the amount of sugar-pine lumber used in various California industries during the year 1910. Exact figures for all industries are not available, but those in the table are sufficiently accurate to give a fairly reliable indication of the value of the species for various purposes. It will be noted that a large percentage of the box lumber is used locally.

With the advent of the sawmill in California, the more accessible stands of sugar pine were eagerly sought by the lumbermen because of the superior quality of the lumber. Its durability, lightness, and softness as compared with other available woods led to its use for shakes, flumes, sluice boxes, bridges, houses, barns, fences, and numerous other purposes. Shingle manufacture has to some extent replaced shake making. The early demand created by the fruit industry for trays and boxes was met largely by the sugar-pine mills. With increased use prices were stimulated, good grades increased in value, and the lower grades were utilized in box making. Because of its color, lightness, and freedom from taste and odor, sugar pine has remained a favorite with raisin packers. Some mills work a portion of their output into raisin trays, some specialize in raisin boxes, and nearly all utilize their poorer grades for box shooks or dispose of them to box makers. About 65,000,000 feet are used in California in bridge construction, sluicing, dimension stock, and general building material.

Because of its straightness, softness, freedom from warping and shrinkage, splendid service when exposed to weather, and fine finishing qualities, sugar pine is a very important wood in the manufacture of special-order sash, doors, and blinds, decks of boats, and general millwork. These same qualities make it valuable for frames and stairwork. For pattern and model making, which require woods easily worked, glued, and nailed, it is a close second to white pine. Fixture manufacturers use it for altars, beading, show cases, counters, veneer cores, shelving, and drawers. Freedom from taste and odor make it especially valuable for druggists' drawers, for compartments for spices, coffee, tea, rice, sugar, and other provisions, and for shelving. Furniture manufacturers turn it into backing, built-in dressers, sideboards, carved work, core stock, table frames, and tops. Tanks, hot-grease vats, troughs, and water boxes, requiring freedom from taste and permanence, are frequently of this wood. Its lightness recommends its use for special trunks and sample cases. Its straight grain and permanence give it a place in the manufacture of piano and pipe-organ keys and actions, and player pianos; and the same qualities, together with lightness, place it among the best woods for drawing boards and extension level rods.

Large quantities are used by planing mills in the manufacture of cut siding, interior finish, and moldings. It takes readily the finest enamel finish.

In addition to the above, sugar pine is used for drainboards, elevator floors, brushes (brush blocks), apiary supplies, machine parts, saddles (saddle trees), shade and map rollers, wood carvings of all kinds, oars, slack cooperage, woodenware, bakers' work boards and troughs, dresser brackets, and small turnings and fencing. A large quantity is made into matches.

SHAKE MAKING.

The manufacture of shakes (hand-split shingles) consumes only a small amount of sugar pine, but the industry is unique and is an interesting survival of pioneer methods. In the days of the forty-niners shingles and other modern roof coverings were, of course, not available. The early settlers, however, soon discovered that the straight-grained sugar pine closely resembled the white pine with which many of them had been familiar in the East or Middle West and could readily be split by hand into rough shingles. Piles of refuse made up of the rougher unusable portions of the tree left scattered throughout the forest still testify to their activity, although the industry has diminished with the coming of transportation and the sawed shingle until now it is only practiced by a few old, skilled workmen, or in localities still remote where other roof coverings are prohibitive in price. Tray boards, used in the manufacture of frames or "trays" for fruit drying, were formerly made to a large extent by hand from sugar pine also. Now, however, small shingle and tray mills are finding their way into the mountains and are taking the place of the hand workman.

The shake or tray maker demands the best straight-grained trees. A number are generally tested by chipping before a suitable individual is found. After felling, the tree is sawed into blocks generally 32 inches long for roof shakes and 24 inches long for tray shakes. The blocks are split into bolts, and these are again divided into sections which will allow of splitting out shakes of the width desired. These sections are then placed in a frame, which holds them firmly, while the workman rives the thin shakes with a heavy wide-bladed knife called a "frow," driven by a hand maul. This process requires much skill, and it is fascinating to watch a skilled workman engaged in it. Roof shakes are usually 32 inches long, 5 inches wide, and three-sixteenths of an inch thick on the inner edge; tray shakes are 24 inches long, 6 inches wide, and one-fourth inch thick.

The making of shakes from green timber results in the waste of about 25 per cent of the tree, and is therefore an undesirable practice. The use of dead sugar pines, both standing and down, for shakes is encouraged by foresters, however, since in this way partial utilization of merchantable material that would otherwise be wasted can be secured.

STUMPAGE PRICES.

Theoretically the stumpage value of a given body of timber is that portion of the difference between the cost of operating and the selling value of the manufactured product remaining after a reasonable profit has been deducted for the operator. National Forest stumpage is appraised on this basis. Thus stumpage values increase or decrease directly as the selling value of the product, and inversely as the cost of operation. Stumpage values, however, trend steadily upward with much less fluctuation than there is in lumber prices.

Generally speaking, the value of the stumpage on different tracts in the same general locality varies with the kind and quality of timber, ease of logging, and general accessibility of the tract to the market.

The value of private stumpage is materially affected by carrying and holding charges, which consist of the cost of fire protection, taxes, and interest. With interest at 6 per cent, the total annual carrying cost is probably about 8 per cent of the value. This annual cost must be compounded; therefore, stumpage must double in value about every decade in order to make the holding of it profitable.

It is only in comparatively recent years that separate stumpage values have been placed on sugar pine as distinguished from yellow pine. The bulk of the pine timberlands in California in private ownership were acquired from the Government under the timber and stone act at $2.50 per acre. These claims were ultimately disposed of to speculators upon an acreage basis which meant anywhere from 10 cents to 20 cents per 1,000 feet board measure. Especially accessible or well-located tracts brought from 30 cents to 50 cents per 1,000 feet. This condition existed until the latter part of the nineties, when more extensive operations brought about a rise in stumpage values. Accessible sugar-pine stumpage in 1900 and 1901 was worth about $1. By 1904 and 1905 private sugar pine stumpage was sold at from 75 cents and $1 in Siskiyou County and the northern Sierras to $1.50 and $1.75 in the southern Sierras. During 1905 considerable sugar pine was sold from the National Forests in the southern Sierras at $2 per 1,000 feet. These same sales included yellow pine at $1.50, white fir at 75 cents, and incense cedar at 50 cents.

The value of privately owned stumpage has increased still further. Sales are now made on the basis of board-measure estimates or actual scale. However, in most transactions sugar pine and yellow pine are included at the same rate, and in many cases a flat rate is still made covering all species. For well-located timber this flat rate is in the neighborhood of $1.75 to $2.25 per 1,000 feet; or sometimes $2.50 per 1,000 feet if the proportion of inferior species is light. Assigning to sugar pine its proper share of this average price would make it worth from $3 to $4 per 1,000 feet. Timber less advantageously located is sold at an average rate of $1.25 to $1.50 per 1,000 feet.

The range of stumpage rates secured for sugar pine in sales of National Forest timber in California made during recent years is as follows:

	Maximum.	Average.	Minimum.
North Coast Range and Sierras	$3.50	$3.40	$2.75
Central Sierras	3.50	2.75	2.50
Southern Sierras	3.50	3.00	2.75

Within the California National Forests extensive bodies of timber containing sugar pine are now being offered for sale, and complete information regarding these tracts can be secured from the district forester at San Francisco, Cal. Operators in National Forest timber are not required to make large advance payments; and the stumpage is not taxed, although the State derives a direct compensating revenue from all sales, through the United States Treasury. Operations in this class of stumpage are somewhat more expensive than on private lands because from 10 to 35 per cent of the younger timber is left on the area, and the piling and burning of refuse is required as well as the cutting of unmerchantable trees which are a fire or disease menace. These costs are taken into account in the appraisal, however, and are borne by the stumpage and not by the operator.

GROWTH AND YIELD.

HEIGHT GROWTH.

One of the most remarkable characteristics of sugar pine is its ability to sustain a rapid rate of growth up to a very advanced age. Its rate of growth in height is comparatively slow; up to about 100 years of age it is less than that of yellow pine. At this point it forges ahead and maintains its lead. In the most favorable situations, during its first century of life, sugar pine makes an average annual height growth of about 1 foot; during its second century, about 0.6 foot; and during its third century, about 0.4 foot.

Foresters are interested principally in the rate of growth in the second-growth stands rather than in virgin stands, since this indicates the possibilities of the species under management. In the case of sugar pine it is very difficult to find representative second-growth stands, because there are but few sufficiently old cuttings and because sugar pine second-growth never occurs in dense young stands as yellow pine does, but always in open, mixed stands where growth is not forced so strongly by competition for light. Table 15 was prepared from analyses of 29 rapid growing, young, second-growth sugar pines. The contrasting yellow pine measurements were taken in thrifty, dense, second-growth stands in Nevada County, Cal.

F—98911

FIG. 1.—LIVING PINE DAMAGED BY RECURRING FIRES, LASSEN COUNTY, CAL.

F—J—D5

FIG. 2.—NATIONAL FOREST TIMBER SALE.

Area after cutting, showing refuse piled for burning and thrifty groups of yellow and sugar

TABLE 15.—*Height growth of saplings and poles in the Sierra Nevada Mountains.*

Age.	Sugar pine total height.	Yellow pine total height.	Age.	Sugar pine total height.	Yellow pine total height.
Years.	*Feet.*	*Feet.*	*Years.*	*Feet.*	*Feet.*
10	4	12	40	62	69
20	19	34	40	73	82
30	45	52	60	82	91

Height measurements of over 700 seedlings and saplings taken on virgin forest areas show the average height of young sugar pines grown under such conditions to be only about 5 feet at the end of 40 years. The above table indicates a height of 62 feet at this age. This startling difference shows that the tree responds quickly to proper conditions of light, soil, and moisture, and is an encouraging indication of what may be accomplished by proper management.

In order to show the height growth of trees over 60 years of age, 287 trees were measured in four representative localities in the virgin forests of the Sierra Nevada Mountains. Table 16 shows the rates of height growth in the best and poorest situations and also the average growth on all plots.

TABLE 16.—*Maximum, minimum, and average heights based on age in virgin California forests (Sierra Nevada Mountains).*

Age.	Total height.			Maximum current annual growth.	Age.	Total height.			Maximum current annual growth.
	Maximum.	Average.	Minimum.			Maximum.	Average.	Minimum.	
Years.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Years.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
20	8	....	....	0.40	220	173	148	127	0.40
40	24	23	....	.80	240	180	153	129	.35
60	49	45	....	1.25	260	187	158	131	.35
80	84	72	61	1.75	280	194	162	132	.35
100	111	92	77	1.35	300	200	167	134	.30
120	127	106	91	.80	320	206	171	135	.30
140	139	118	103	.60	340	212	174	136	.30
160	148	127	112	.45	360	218	177	137	.30
180	157	135	119	.45	380	....	180	....	....
200	165	142	124	.40	400	....	183	....	....

It is evident that the period of most rapid growth is from the eightieth to the hundredth year of life in the best localities, at which time the annual increase in height amounts to 1.75 feet. At the age of about 110 years the rate of height growth has fallen off to such an extent that current annual growth is less than the mean annual growth or average annual growth for the entire growing life of the tree.

MERCHANTABLE AND CLEAR LENGTHS.

From a commercial standpoint the merchantable length of a species (the length of that section of the tree which can be utilized and the clear length free from limbs and yielding high-grade lumber) is more important than the total height. Because of its straightness, a very large proportion of the bole of a sugar pile can be utilized. Furthermore, the lower branches of the crown fall off at a comparatively early age, leaving an unusual clear length averaging 50 feet in nature stands and not infrequently reaching 80 feet. A table, based on a large number of actual measurements, showing the merchantable length of trees of various diameters and heights will be found in the Appendix.

DIAMETER GROWTH.

Sugar pines of the largest diameters are found on the best sandy loam soils in fairly open situations. Trees in dense forest, in competition with others for light, are obliged to devote their energy to height growth largely. Table 17 shows maximum, average, and minimum diameters based on age in virgin stands.

TABLE 17.—*Minimum, average, and maximum growth in diameter, on basis of age, California.*

Age.	Diameter breast-high outside bark, in inches.			Age.	Diameter breast-high outside bark, in inches.		
	Maximum.	Average.	Minimum.		Maximum.	Average.	Minimum.
Years.				*Years.*			
20	0.4	0.2	....	260	60.1	44.9	32.4
40	4	2.5	....	280	63.5	47.2	34.3
60	9.7	7.5	5.8	300	66.9	49.3	36.1
80	16.7	13.0	9.2	320	70	51.4	37.9
100	24.1	18.1	12.6	340	73.3	53.5	39.5
120	30.4	22.7	16.2	360	76.1	55.5	....
140	35.6	26.8	19.2	380	....	57.3	....
160	40.3	30.5	21.8	400	....	59.1	....
180	44.9	33.9	24.2				
200	49.1	37.0	26.4				
220	52.8	40.0	28.6				
240	56.5	42.5	30.5	Number of stump analyses	20	474	22

The measurements upon which Table 17 is based were taken for the purpose of showing the effect of locality upon diameter growth rather than the effect of various factors, such as soil, light, and moisture, within a given locality. The maximum measurements were secured among dominant trees within the western central Sierras, the best range of the species. The minimum measurements were taken among the same class of trees in Siskiyou County, northern California, toward the limit of the range. The average was obtained by averaging the measurements taken in eight localities throughout the State. The effect on the growth of unfavorable factors within a given locality approximates the effect of an unfavorable change in latitude or altitude, however; therefore, the average growth shown in the tables is indicative of the growth that trees somewhat crowded for light, or growing on poorer soils, might make in a more central portion of the range of the species. In the same way, the minimum figures represent roughly the results under a still greater degree of light or soil suppression.

It appears from the diameter-growth table that the maximum current diameter growth occurs between 80 and 100 years, which is also the period of maximum height growth. The maximum average annual growth for this 20-year period is 0.37 inch. The rate of growth in diameter decreases less rapidly, however, than the rate of height growth, the current annual exceeding the mean annual growth up to about the hundred and forty-fifth year. Usually the height growth of a tree species culminates before the diameter growth. Whether the sustained rate of height growth apparent in this species is attributable to the fact that the trees measured grew in virgin forest, where their light requirements were not satisfied during youth, or whether this is an inherent peculiarity, has not yet been fully determined, and can not be until older, more normal second-growth stands are available for study.

VOLUME GROWTH.

Table 18, showing the growth in volume of sugar pine, is derived from tables of average growth in diameter and height at various ages and a volume table for trees of various diameters and heights (see p. 37–38, Appendix). The striking feature shown by this table is the great age to which the tree sustains volume production. The current annual volume growth remains above the mean annual growth for over 400 years, over 300 years after height and diameter growth have culminated. At 100 years of age the annual rate of volume growth is 2 cubic feet. It then increases steadily up to an annual rate of 5½ cubic feet at 350 years. The rate of volume growth remains practically constant from that age up to 460 years. No information to indicate its behavior at a greater age has been collected.

TABLE 18.—*Growth in volume, on the basis of age, diameter, and height of average dominant trees, California Sierras.*

Age.	Average.		Volume.		Age.	Average.		Volume.	
	Diameter outside bark at breast height.	Total height.	Cubic feet outside bark.	Board feet (Scribner Decimal C rule).		Diameter outside bark at breast height.	Total height.	Cubic feet outside bark.	Board feet (Scribner Decimal C rule).
Years.	*Inches.*	*Feet.*			*Years.*	*Inches.*	*Feet.*		
20	0.2	8	....	....	220	40.0	148	530	2,830
40	2.5	23	....	....	240	42.5	153	630	3,460
60	7.5	45	....	....	260	44.9	158	733	4,120
80	13.0	72	31	110	280	47.2	162	838	4,840
100	18.1	92	71	240	300	49.3	167	944	5,570
120	22.7	106	126	490	320	51.4	171	1,050	6,020
140	26.8	118	192	850	340	53.5	174	1,158	7,750
160	30.5	127	268	1,290	360	55.5	177	1,270	7,740
180	33.9	135	318	1,760	380	57.3	180	1,380	8,389
200	37.0	142	435	2,250	400	59.1	183	1,488	9,010

Table 19 indicates the comparative rate of volume, diameter, and height growth of sugar pine and two of its common associates, yellow pine and incense cedar. Sugar pine evidently outgrows cedar in all three respects from its fiftieth year. It passes yellow pine in height about the one hundred and tenth year, in diameter about the one hundred and thirtieth year, and in volume about the one hundred and fiftieth year.

TABLE 19.—*Comparative rate of volume, diameter, and height growth of sugar pine and two of its common associates.*

Age.	Species.								
	Sugar pine.			Yellow pine.[1]			Incense cedar.		
	Diameter breast high.	Height.	Volume.	Diameter breast high.	Height.	Volume.	Diameter breast high.	Height.	Volume.
Years.	*Inches.*	*Feet.*	*Board feet.*	*Inches.*	*Feet.*	*Board feet.*	*Inches.*	*Feet.*	*Board feet.*
20	0.2	8	....	2.3	12	....	....	....	....
40	2.5	23	....	6.5	29	....	3.2	....	....
60	7.5	45	....	11.4	57	....	6.4	23	....
80	13.0	72	110	16.1	79	210	9.8	49	....
100	18.1	92	240	20.0	94	360	13.6	65	70
120	22.7	106	490	23.3	104	610	17.8	75	140
140	26.8	118	850	25.8	112	890	21.3	82	230
160	30.5	127	1,290	28.0	118	1,170	23.6	86	310
180	33.9	135	1,760	29.8	123	1,430	25.8	90	390
200	37.0	142	2,250	31.3	127	1,640	27.8	93	490
220	40.0	148	2,830	....	....	....	29.8	96	600
240	42.5	153	3,460	....	....	....	31.7	98	720
260	44.9	158	4,120	....	....	....	33.6	101	850
280	47.2	162	4,840	....	....	....	35.4	103	970
300	49.3	167	5,570	....	....	....	36.9	105	1,090
320	51.4	171	6,020	....	....	....	38.2	115	1,200
340	53.5	174	7,050	....	....	....	39.2	118	1,290
360	55.5	177	7,740	....	....	....	40.1	119	1,380
380	57.3	180	8,380	....	....	....	40.9	120	1,440
400	59.1	183	9,010	....	....	....	41.6	121	1,510

[1] From Forest Service Bul. No. 69, "Sugar Pine and Western Yellow Pine in California," by Albert W. Cooper.

YIELD.

The average merchantable stand per acre of sugar pine varies widely throughout its range. In general it ranges from 2,000 to 16,000 board feet, which represents from 12 to 60 per cent of the total stand. However, within the sugar pine-yellow pine type considerable areas show an average of 20,000 feet per acre, representing 40 per cent of the whole

TABLE 20.—*Maximum stands of sugar pine within the sugar pine-yellow pine type in three localities.*

Locality.	Western yellow pine.		Sugar pine.		White fir.		Incense cedar.		Douglas fir.		Total.	
	Bd. ft.	*P. ct.*	*Bd. ft.*	*P. ct.*	*Bd. ft.*	*P. ct.*	*Bd. ft.*	*P. ct.*	*Bd. ft.*	*P. ct.*	*Bd. ft.*	*P. ct.*
Tahoe National Forest	11,030	22.7	18,440	37.9	7,174	14.8	1,880	3.9	10,050	20.7	48,574	100
Stanislaus National Forest	13,750	27.4	20,700	41.2	11,370	22.6	4,430	8.8	....	....	50,250	100
Yosemite National Park	14,688	23.9	20,538	33.4	19,269	31.4	6,904	11.3	....	....	61,399	100

Table 20 shows maximum stands of sugar pine within the sugar pine-yellow pine type in three representative Sierra Nevada range localities, as well as the proportion of other species in mixture.

The heaviest single acre estimate of which the Forest Service has a record is 192,000 feet b. m., which amounted to 75 per cent of the total estimate for the acre plot. Acres containing 75,000 to 150,000 feet b. m. are frequently found within the maximum range of the species. The largest single tree measured by the Forest Service scaled 40,710 feet b. m.

TABLE 21.—*Yellow pine type (quality II). Yield per acre and increment per acre per annum of all species.*

Age.	Yield per acre.	Increment per acre per annum.	Age.	Yield per acre.	Increment per acre per annum.	Age.	Yield per acre.	Increment per acre per annum.
Years.	*Bd. ft.*	*Bd. ft.*	*Years.*	*Bd. ft.*	*Bd. ft.*	*Years.*	*Bd. ft.*	*Bd. ft.*
10	55	5.5	150	15,900	106	290	33,200	114.5
20	220	11	160	17,900	112	300	33,300	111
30	550	18	170	19,900	117	310	33,200	107
40	1,000	25	180	21,900	122	320	33,000	103
50	1,600	32	190	23,800	125	330	32,600	99
60	2,600	43	200	25,600	128	340	32,200	94.5
70	3,500	50	210	27,200	129.5	350	31,700	90.5
80	4,600	57	220	28,700	130.5	360	31,100	86.5
90	5,900	66	230	29,800	130	370	30,500	82.5
100	7,300	73	240	30,900	129	380	29,900	78.5
110	8,800	80	250	31,700	127	390	29,200	75
120	10,400	87	260	32,300	124	400	28,500	71.2
130	12,100	93	270	32,800	121			
140	14,000	100	280	33,100	118			

TABLE 22.—*Fir-sugar pine type (quality II). Yield per acre and increment per acre per annum of all species.*

Age.	Yield per acre.	Increment per acre per annum.	Age.	Yield per acre.	Increment per acre per annum.	Age.	Yield per acre.	Increment per acre per annum.
Years.	*Bd. ft.*	*Bd. ft.*	*Years.*	*Bd. ft.*	*Bd. ft.*	*Years.*	*Bd. ft.*	*Bd. ft.*
10	80	8	230	40,500	176	450	88,400	196.5
20	300	15	240	43,700	182	460	88,700	193
30	700	23	250	47,000	188	470	88,700	189
40	1,300	32	260	50,300	193.5	480	88,500	184
50	2,000	40	270	53,600	198.5	490	88,200	180
60	2,900	48	280	57,000	203.5	500	87,700	175.5
70	3,900	56	290	60,200	207.5	510	87,000	170.5
80	5,100	64	300	63,500	211.5	520	86,200	165.5
90	6,500	72	310	66,500	214.5	530	85,200	161
100	8,000	80	320	69,200	216	540	84,100	155.5
110	9,600	87.5	330	71,800	217.5	550	82,800	150.5
120	11,400	95	340	74,200	218	560	81,500	145.5
130	13,400	103	350	76,300	218	570	80,100	140.5
140	15,500	111	360	78,300	217.5	580	78,700	135.5
150	17,800	118.5	370	80,100	216.5	590	77,300	131
160	20,200	126	380	81,700	215	600	75,900	126.5
170	22,600	133	390	83,200	213.5	610	74,500	122
180	25,200	140	400	84,500	211.5	620	73,100	118
190	28,000	147.5	410	85,700	209	630	71,600	113
200	31,000	155	420	86,600	206	640	70,000	109.5
210	34,000	162	430	87,400	203			
220	37,200	169	440	88,000	200			

Since sugar pine never occurs in pure or even-aged stands, the problem of predicting the acreage yield at various ages is a complex one which has not as yet been satisfactorily solved. Tables 21 and 22 indicate the probable yield of all species in the yellow pine and fir-sugar pine types of which this species forms a part. They were prepared from data collected on the Plumas Forest (Plumas County, Cal.) during 1912 and represent results on areas of average productiveness.[1]

These tables indicate that the maximum volume is produced at 300 years in the yellow-pine type and at 460 years in the fir-sugar pine type. The highest rate of volume production, however, occurs at 180 years in the former type and at 280 years in the latter.

MANAGEMENT.

The manner in which any tract of forest land is handled depends, of course, entirely upon the wishes or necessities of its owner. If present financial considerations demand it, clear cutting of all merchantable trees must be practiced. Some lumbermen, by following this policy, jeopardize the future of the forest, encourage species of low value, and postpone a second cut for at least a century. If esthetic considerations govern, then expenditures may be made which will never yield a direct monetary return. If, however, the owner desires to make his manufacturing business permanent and is willing partially to subordinate present to future returns, he must determine what classes of trees can be most profitably left to furnish seed, shade, and a second cut; what protective measures are necessary and practicable to prevent the destruction of the trees left, both during logging and later; and what amount he can spend annually or periodically in artificial reforestation or thinnings if necessary. There is a marked tendency now toward close utilization of all pines cut, toward leaving trees that are evidently immature, and toward protecting the remaining stand from fire and insects.

High taxes tend to prevent the practice of management on private lands. Naturally lumbermen can not afford to hold land for a second cut when taxes and other carrying charges will in the meantine amount to more than the possible prospective profit. With low taxes and carrying charges operators can afford to leave and to protect young trees and trees of inferior species until they become more valuable. Since lands in Federal ownership are not burdened with as heavy carrying charges as private holdings, and since it is the evident duty of the Government to experiment and lead in the field of forestry, the cuttings on the National Forests are naturally the best examples of present-day forest-management methods.

NATIONAL FOREST METHODS.

The following principles govern cutting in the sugar-pine type on National Forests:

It is the general aim to improve the forest by cutting so as to put it in condition to produce a sustained yield in future years when that becomes necessary.

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[1] See Appendix to Plumas Working Plan, by Barrington Moore, forest assistant, February, 1913.

The exact age at which sugar pine and the various species which enter into combination with it should be cut to yield the highest return is dependent upon so many variable factors that it is impossible to determine it with accuracy at present. Even if this were determinable, however, such a cutting age (rotation) could not be strictly adhered to, because, under present economic conditions, demand and accessibility must largely determine the time and place of cutting. We know, however, that stands of yellow pine and sugar pine reach their highest rate of volume production at about 180 years. On average sites the diameter of sugar pine is approximately 33 inches, and of yellow pine 30 inches at this age. White fir and cedar, the two other principal species in mixture, while not so large at this age, are of merchantable size and usually in need of cutting on account of their susceptibility to disease. Therefore, without danger of serious error, stands in which sugar pine is an important tree may be cut down to a diameter of about 30 inches.

This principle is used as a guide in the cutting done in such stands within the National Forests, although the removal of smaller trees and the leaving of larger is practiced whenever necessary for a weighty special reason, such as the elimination of disease or the creation of conditions favorable to reproduction. Diseased trees are always cut and the merchantable portions utilized, since sanitation is as essential to health in a forest as in a human community. Dead trees are a source of danger in time of fire and are felled. The cost of this work to operators—generally from 3 to 7 cents per 1,000 feet—is taken into account in fixing the stumpage rate.

Timber apparently ripe is always harvested, except when it is clear that reproduction can not be secured on the area unless a few trees of this class are left for seed or shade. The condition of the crown of the tree determines which individuals are to be cut. Trees whose crowns are flattened are mature, or are not making profitable growth, and should be removed. It is recognized that sufficient timber must be secured from each tract to make the operation profitable. While this amount varies with the investment and with logging conditions, from 12,000 to 18,000 feet per acre is usually a profitable cut. The removal of this amount should leave a sufficient basis of younger trees for a second cut in from 50 to 60 years. It is expected that lumber prices will have increased by that time to a point which will allow of operating at a profit for a smaller per acre yield.

Practical considerations demand that trees so situated as to be a hindrance to carrying out the most feasible and economical logging plan be cut whether mature or not. This practice is followed in preference to leaving such trees to inevitable injury, which will lessen their growth and perhaps cause disease.

Studies of the grades cut from pine logs of various dimensions indicate that knotty trees under 32 inches in diameter produce largely common and box lumber, which can be marketed at present only at a loss or at a very slight profit. Such trees may profitably be left for seed or protection and to form a part of the next cut, for which they will be more valuable because of increased growth, higher selling prices, and a greater percentage of high-grade product as the result of natural pruning.

The white fir and cedar in sugar-pine stands are now difficult to market at a profit above the bare cost of production. Both of these species have greater prospective than present values—the former for pulp as well as lumber, the latter for pencil stock and other refined uses. It appears to be wise management, therefore, to remove only the dead, diseased, and mature trees which will not remain merchantable until the next cut. Young sugar pine reproduction requires shade in youth, and these species are left to furnish it in preference to others of more value. Their reproduction will endure shade, and is therefore a valuable agent in preventing brush from securing control of cut-over areas.

In applying the above principles on National Forests the cutting is so regulated as to create conditions favorable to the securing of a stand of young trees through natural regeneration, because the perpetuation of the forest depends upon this. Sugar-pine seed is eaten in large quantities by rodents and birds, and since young trees require protection from too severe light for the first 10 years of their life the securing of young growth is rather a difficult problem. Eventually, when transportation and market conditions allow of cutting over areas frequently for a small volume of timber, the shelterwood system of cutting will probably be applied where sugar pine makes up 20 per cent or more of the stand. This system provides for several successive operations separated by short intervals; the first opens up the stand slightly to afford just sufficient light to stimulate the seed-producing capacity of the remaining trees and to secure young growth; the second follows after reproduction has been secured and partially frees it from shade; the third removes the remaining mature trees. At present, however, this system would not pay.

In the sugar-pine type the forest is made up of groups of mature sugar pine and its common associates, interspersed with openings and approximately even-aged groups of younger trees of the same composition, as well as of trees of various ages and species occurring singly. On areas where the occurrence is in groups the clumps of mature trees are cut clean and the immature are left. Sometimes it is necessary to leave a mature tree which may occur in an immature group from which it could not be removed, or to remove a few immature trees from mature groups because of the likelihood of wind damage or to free reproduction from shade. In cuttings of this nature the reproduction of the more light enduring species, such as yellow pine, white fir, and Douglas fir, take possession of the openings first, and young sugar pines are confined to the zone of partial shade around the groups left. Later, after partial shade has been established in the openings, some sugar pine enters the mixture and tends eventually to outdistance the other trees because of a more rapid and sustained rate of growth. This method of cutting is known as the group-selection system. Generally from 65 to 75 per cent of the board-measure content of the stand is removed.

On areas covered with trees of various ages mingled together the so-called selection system of cutting must be applied. Each tree is subjected to the test of maturity, health, and value of contents. Mature and unhealthy trees are removed. Immature trees, or trees of the less valuable species, such as fir and cedar, are left to furnish shade and protection. Whenever it is necessary to remove a few pines not fully mature in order to make the operation profitable, those that will yield the highest grade product are selected.

Such a cutting results in maximum openings of an acre in the forest cover and in the removal of from 75 to 85 per cent of the mature stand. These openings will, it is believed, on fairly favorable situations restock with yellow pine, fir, and cedar, followed by sugar pine when proper shade conditions have been established, as in the group-selection system.

UTILIZATION.

While logging on private lands is still wasteful, utilization is far more complete than it was 10 or 15 years ago. At that time only the larger pine trees were cut. Stumps were sometimes cut as high as 4 feet and only the clear length of the trees removed. Wasteful lumbering in the past has been due primarily to low stumpage values and poor market conditions. The cost of transportation has been another important factor, since only the better class of material could be hauled to market at a profit.

With the rapid growth of the lumber industry in California more modern methods of logging have been adopted. Some concerns cut only the best fir and cedar, but pines are frequently utilized to a diameter of 10 inches in the tops. Stumps are usually cut from 18 to 24 inches high. Even tops and limbs are, in favorable localities, utilized for firewood.

In sales of National Forest stumpage the closest utilization consistent with modern logging methods and market conditions is practiced. Stumps are cut 18 inches or less in height; trees are utilized to a top diameter of at least 10 inches in the case of pines and 12 inches for other species, and all species are logged. Pine logs which contain 33 per cent, and logs of other less valuable species which contain 50 per cent sound lumber, are considered merchantable.

PROTECTION.

No scheme of management should be undertaken or can be successfully carried out unless the area involved is adequately protected from destructive influences. Fire, insects, and disease are the most active agents of tree destruction. Of these, fire is the most important, because it not only kills all young growth and injures or kills mature trees, but also depletes the soil by consuming the humus, and destroys other forms of property as well as life. Within the National Forests of California during 1914, 1,304 fires occurred, causing an estimated loss of about $77,000.

Virgin stands in which no cutting is being done should be protected by eliminating the causes of fire as much as possible by the use of suitable warning signs and other regulation and by a systematic patrol for the detection of fires. The efficiency of any patrol is considerably increased by installing telephone lines and by a good system of roads and trails constructed, wherever possible, so as to act as firebreaks. Under such conditions one patrolman, at a salary of $300 for himself and horse for the danger season of four months, should take care of from 25,000 to 30,000 acres. An adequate patrol system should not cost over 2 cents per acre per annum.

Fire risk naturally increases when lumbering operations start, because of the presence of engines and men as well as slash. Precautions are therefore particularly necessary. The most effective precaution is the disposal of slash by burning. On National Forest sale areas in California all slash is piled at once in tepee-shaped piles and burned at a favorable season. This operation costs from 20 to 30 cents per 1,000 feet board measure.

All engines used in connection with logging should, when possible, burn oil. If this is not feasible, they should be equipped with adequate spark arresters and with hose and water under pressure for putting out fires which start in their vicinity. Supplies of shovels and axes should be readily available at convenient points about the operation.

The importance of the control of insects and tree diseases is only secondary to the control of fire in managed forests.

PLANTING.

On treeless areas, or where natural reproduction can not be secured by leaving seed trees, planting must be undertaken. Thus far, in California, National Forest tree planting has been confined principally to treeless areas which once undoubtedly bore forests. The brush fields common in northern California are representative of this type of land. On pine lands where practically all of the trees are mature it may be found after planting methods have been perfected and cheapened that it is more profitable to cut all of the timber and plant, but at the present time this is not considered feasible.

In a year when sugar-pine seed is plentiful it can be collected in large quantities from felled trees or from standing trees by climbing and cutting off the cones with an improvised cutting knife on a pole for from 50 to 60 cents per pound. Collecting small quantities is more expensive.

Attempts have been made to restock denuded areas with sugar pine by sowing the seed directly in the field either broadcast or in prepared seed spots. Both of these methods have failed absolutely. The seed has either been devoured by rodents before germination or the young trees have succumbed to the effect of drought during the first season.

A small supply of sugar-pine stock for field planting is now being produced annually at the Pilgrim Creek Nursery, near McCloud, Cal., on the Shasta Forest, and experiments in planting have been conducted near there and also in Plumas County. So far it has been very difficult to produce satisfactory trees, both because the seed germinates very slowly and incompletely and on account of the unsatisfactory development of the seedlings and transplants. Results indicate that 3-year-old trees are the best adapted to field conditions. Plantations of 3-year-old trees have cost, on an average, about $22 per acre, including all items. This cost is excessive and is only justified by the value of the experiments. If this preliminary work is fairly successful, costs can be decreased as the scale of work is increased.

MANAGEMENT OF PRIVATE TIMBERLANDS.

Private timber holdings may be divided into two principal groups—individual holdings and corporate holdings. The individual holdings are generally smaller than the corporats ones, and it is usually the natural desire of individual holders to secure all possible profit from their lands during a lifetime. It is undoubtedly just as good business for such owners to protect their capital (standing merchantable timber) against loss as it is for the proprietor of any other business to carry insurance. Protection of cut-over areas, except in so far as is necessary to prevent the loss of merchantable timber adjoining or equipment, however, is not at present profitable to this class of owners.

Corporations may look further into the future, since their life is indefinite. Thus far they have found it more profitable to extend their operating life by adding to their holdings rather than to attempt to maintain their cut-over lands in such a condition of productiveness that a profitable second crop can be derived from them by the time the entire area has been cut over. It is self-evident, however, that as the supply of stumpage decreases its value will increase until it equals the cost of producing timber. It is fair to assume, therefore, that a reasonable present outlay in immature timber left on cut-over areas and in the protection of these areas will show a return at that time, or at least that the stumpage thus produced will be as cheap as that obtainable by purchase.

In order to secure a second crop within a reasonable time in the sugar pine-yellow pine type, owners should follow the Forest Service methods of cutting as closely as the necessities of their business will allow, particularly as regards close utilization, leaving immature timber and timber of species which have a greater prospective than present value, such as white fir and cedar.

On areas cut over conservatively protection from fire must be provided. Promiscuous burning of the slash has been frequently advocated. This method involves the destruction of a large amount of young growth and serious injury to trees left standing, and therefore can not be indorsed. Careful piling and burning of brush, the method practiced by the Forest Service, at a cost of 25 cents per 1,000 feet, is probably too expensive for private owners. A compromise between these two methods should prove fairly effective. The brush on portions of cut-over areas located where there is unusual fire risk should be roughly piled away from living trees and clumps of young growth and carefully burned after the fall rains, when fires can be controlled. Piling and burning of this character can be accomplished for from $1 to $1.50 per acre. On all other portions of the cut-over area the slash should be distributed over the ground as evenly as possible when the trees are trimmed and measures adopted to prevent fires or to put out quickly those that are started.

The Forest Service offers to protect, under cooperative agreement, the lumber holdings of owners of areas within California National Forests at a cost of from 1½ to 4 cents per acre, and will also gladly give advice to those who wish to install an independent scheme of protection.

APPENDIX.

VOLUME TABLE.

Table 23 is based upon actual measurements of 910 felled sugar-pine trees, taken by the Forest Service in California. No allowance was made for defect. In field estimating trees are tallied by two inch, breast-high (4.5 feet), diameter classes, and by the number of logs they contain. Their contents in feet board measure may then be obtained from this table.

TABLE 23.—*Sugar pine (Pinus lambertiana), Lassen, Plumas, Sierra, Stanislaus, and Tahoe National Forests, Cal. Curved, Scribner Decimal C.*

Diameter breast high.	Number of 16-foot logs.												Diameter inside bark of top.	Basis.
	1	2	3	4	5	6	7	8	9	10	11	12		
	Volume—Board feet in tens.													
Inches.													*Inches.*	*Trees.*
10	4	8												
12	4	9	15	22									8	
14	5	10	17	24									8	1
16	6	10	19	27	39								8	2
18	7	13	20	30	43								9	7
20	8	17	25	37	50	65	79						9	28
22	10	22	31	43	57	74	89						9	23
24	13	28	40	53	67	83	100	122					9	35
26		35	50	64	78	96	113	136					9	35
28		45	63	78	92	110	128	152					10	44
30		55	80	94	108	125	144	170	189				10	53
32			95	113	127	145	163	192	218				10	50
34			115	135	149	166	187	217	247				10	38
36			140	160	173	191	213	246	279	310			11	36
38			168	183	200	220	245	278	313	346			11	40
40			195	210	229	253	280	313	349	386			11	41
42				240	261	288	319	354	390	427	463		11	43
44				271	295	325	359	398	435	473	515		12	39
46				303	330	365	401	445	482	523	567		12	31
48				337	366	405	446	493	532	576	623		12	43
50				368	401	446	493	544	586	630	681	749	12	41
52				400	438	489	544	598	642	686	740	818	12	56
54				432	472	532	597	653	698	742	801	885	13	36
56				465	510	575	652	711	756	800	862	953	13	25
58					550	619	709	769	814	860	923	1,022	13	25
60					590	660	764	829	872	921	987	1,090	14	28
62					630	704	820	886	930	983	1,051	1.159	14	25
64					670	760	876	943	990	1,046	1,116	1,227	14	27
66						820	933	1,000	1,053	1,109	1,181	1,297	14	11
68						890	989	1,058	1,115	1,173	1,250	1,366	15	9
70						960	1,018	1,117	1,177	1,239	1,319	1,434	15	17
72						1,030	1,110	1,176	1,240	1,305	1,388	1,502	15	6
74							1,175	1,235	1,303	1,370	1,456	1,570	16	2
76							1,235	1,296	1,368	1,435	1,523	1,639	16	6
78							1,290	1,358	1,431	1,500	1,590	1.707	16	4
80							1,318	1,420	1,497	1,565	1,659	1,778	16	3
														910

Average stump height 1.3 to 3.1 feet.
Logs scaled in commercial lengths as cut.
Figures outside heavy lines are from extension of original table.

TABLE 23.—*Sugar pine (Pinus lambertiana), Lassen, Plumas, Sierra, Stanislaus, and Tahoe National Forests, Cal. Curved, Scribner Decimal C*—Continued.

Diameter breast high.	Total height of tree—Feet.															Diameter inside bark of top.	Basis, trees.
	40	50	60	70	80	90	100	110	120	130	140	160	180	200	220		
	Volume—Board feet in tens.																
Ins.																*Inches.*	
12	6	7	8	10	13	15	18	......	......	......	......	......	......	......	......	8	...
14	7	8	9	10	14	16	20	......	......	......	......	......	......	......	......	8	1
16	8	9	10	12	17	20	24	28	33	......	......	......	......	......	......	8	1
18	....	10	12	16	20	23	29	33	39	......	......	......	......	......	......	9	7
20	....	12	15	20	25	30	35	40	47	60	71	......	......	......	......	9	28
22	....	17	21	27	33	37	42	48	57	68	80	......	......	......	......	9	22
24	....	....	31	36	41	46	50	59	69	79	90	......	......	......	......	9	35
26	....	....	42	46	52	57	63	72	82	93	103	126	......	......	......	9	35
28	....	....	....	58	65	70	78	87	97	109	120	143	......	......	......	10	44
30	....	....	....	72	80	86	96	103	115	128	140	163	......	......	......	10	52
32	....	....	....	86	95	105	115	125	136	149	160	187	230	......	......	10	50
34	....	....	....	100	114	127	138	148	160	172	183	213	260	......	......	10	37
36	....	....	....	120	136	150	162	174	185	198	209	241	293	......	......	11	36
38	....	....	....	144	160	173	189	202	214	225	237	273	328	366	......	11	40
40	....	....	....	....	182	195	214	233	247	257	270	310	363	408	......	11	40
42	....	....	....	....	205	217	240	264	280	293	308	350	402	452	......	11	42
44	....	....	....	....	....	240	268	294	317	333	350	395	449	501	554	12	38
46	....	....	....	....	....	263	296	323	352	377	399	444	500	553	613	12	32
48	....	....	....	....	....	286	325	351	389	422	449	500	557	609	670	12	43
50	....	....	....	....	....	310	355	380	427	470	501	559	615	667	728	12	41
52	....	....	....	....	....	......	......	407	463	521	555	618	676	726	786	12	56
54	....	....	....	....	....	......	......	435	500	576	612	679	736	785	846	13	34
56	....	....	....	....	....	......	......	463	537	633	671	738	797	847	908	13	25
58	....	....	....	....	....	......	......	491	574	693	730	797	859	910	973	13	25
60	....	....	....	....	....	......	......	......	......	751	788	857	920	976	1,040	14	27
62	....	....	....	....	....	......	......	......	......	811	845	917	983	1,040	1,106	14	25
64	....	....	....	....	....	......	......	......	......	873	904	977	1,044	1,104	1,173	14	27
66	....	....	....	....	....	......	......	......	......	937	965	1,034	1,105	1,168	1,240	14	11
68	....	....	....	....	....	......	......	......	......	1,003	1,027	1,091	1,165	1,229	1,305	15	9
70	....	....	....	....	....	......	......	......	......	1,070	1,090	1,150	1,224	1,290	1,370	15	16
72	....	....	....	....	....	......	......	......	......	1,140	1,154	1,212	1,284	1,352	1,434	15	6
74	....	....	....	....	....	......	......	......	......	1,210	1,220	1,273	1,345	1,414	1,497	16	2
76	....	....	....	....	....	......	......	......	......	......	......	1,336	1,408	1,479	1,560	16	5
78	....	....	....	....	....	......	......	......	......	......	......	1,398	1,471	1,543	1,624	16	4
80	....	....	....	....	....	......	......	......	......	......	......	1,460	1,533	1,607	1,689	16	3
																	899

The following table is inserted to show the relation between diameter, total height, and merchantable length of sugar-pine trees:

TABLE 24.—*Merchantable length and diameter of top logs inside bark, sugar pine.*

Diameter breast high.	Total height.[1]	Merchantable length.	Average top diameter inside bark.	Basis number of trees.	Diameter breast high.	Total height.[1]	Merchantable length.	Average top diameter inside bark.	Basis number of trees.
Inches.	*Feet.*	*Feet.*	*Inches.*	*No.*	*Inches.*	*Feet.*	*Feet.*	*Inches.*	*No.*
8	48	[2] 23	....	....	40	148	120	11	41
10	57	[2] 30	....	....	42	152	125	11	43
12	67	[2] 38	....	....	44	156	130	12	39
14	77	45	8	1	46	160	134	12	31
16	86	52	8	2	48	164	138	12	43
18	92	58	9	7	50	168	143	12	41
20	98	65	9	28	52	172	147	12	56
22	104	72	9	23	54	175	151	13	36
24	110	78	9	35	56	178	155	13	25
26	116	84	9	35	58	182	159	13	25
28	121	90	10	44	60	185	163	14	28
30	126	95	10	53	62	188	167	14	25
32	131	100	10	50	64	191	170	14	27
34	136	105	10	38					
36	140	110	11	36	Total	....	....	....	852
38	144	115	11	40					

[1] Basis 287 trees.

[2] Extension of curve.

KEY FOR THE IDENTIFICATION OF SUGAR PINE, WESTERN WHITE PINE, AND WHITE PINE WOODS.

The following key for distinguishing the wood of sugar pine from that of the western and eastern white pine is based chiefly upon characteristics visible under the compound microscope, but all available gross characteristics are also included, and it is believed that these will enable the layman to distinguish the three species. The microscopic characteristics will, of course, be useful mainly to technically trained students. The minute characteristics are often so variable that the student may have considerable difficulty unless he takes into account every characteristic cited in the key and make numerous careful measurements. There is also a good deal of variation in the general gross appearance of the wood of these three pines, but those who are thoroughly familiar with their gross characteristics visible in the rough and finished states will be able to distinguish them quite readily.

Pits on the radial walls of the pith-ray cells two, or sometimes one, per tracheid, round, occurring side by side. Pith rays (tangential section) one to twelve, or often sixteen cells in height. Resin canals about 0.13 to 0.16 mm. in diameter. Wood yellowish white, or often very light brown, with rather coarse grain. Resin canals conspicuous, appearing on a smooth longitudinal surface as dark lines. Sugary exudations and resin pockets common. Weighs about 23 pounds per cubic foot................SUGAR PINE (*Pinus lambertiana*).

Pits on the radial walls of the pith-ray cells one, two, or occasionally three per tracheid, nearly round, and usually placed irregularly. Pith rays (tangential section) one to seven, or sometimes ten, cells in height. Resin canals about 0.13 to 0.15 mm. in diameter. Wood light brown or reddish, with rather fine grain. Resin canals not numerous and slightly less conspicuous than in the one above. No sugary exudation. Weighs about 24.5 pounds per cubic foot................................WESTERN WHITE PINE (*Pinus monticola*).

Pits on the radial walls of the pith-ray cells one, rarely two, per tracheid, large and mostly oblong. Pith rays (tangential section) mostly one to twelve, or sometimes fourteen, cells in height. Resin canals about 0.08 to 0.12 mm. in diameter. Wood cream yellow, or that from very old trees light brown, slightly tinged with red. Resin canals not very conspicuous and no sugary exudations. Weighs about 24 pounds per cubic foot..WHITE PINE (*Pinus strobus*).

GRADES.

Sugar pine lumber is classified into the following grades:

Thick finish:
- No. 1 and 2 clear. 1, 1¼, 1½, 2 inch widths.
- No. 3 clear. Same dimensions; must contain 70 per cent No. 1 door cuttings of No. 1 shop common sizes.
- C select. Same dimensions, one face finished; admits small defects.
- D select. Same as C select, except admits more serious defects.

Siding:
- 1 and 2 grade (B and better). Thickness ½ inch.
- No. 3 siding. Thickness ½ inch; admits greater defects than 1 and 2.

Factory plank or shop common, graded for door cuttings:
- No. 1 shop common. From 50 to 70 per cent No. 1 cuttings.
- No. 2 shop common. Either 25 per cent No. 1 door cuttings or 40 per cent No. 1 and 2 combined, or 50 per cent No. 2.
- No. 3 shop common. 1¼ inch and thicker; not less than 12½ per cent No. 1 and 2 sash and door cuttings.
- Inch shop common. Must contain 50 per cent above described cuttings; cuttings must be 10 inches wide or wider, 22 inches long or longer; or, 8 inches wide or wider and 3 feet long or longer.
- No. 1 fencing D and M. Sound No. 1 fencing worked to flooring; when worked should be of character of No. 1 common strips.
- No. 2 fencing D and M. No. 2 fencing worked to flooring of character No. 2 common strips.
- No. 3 fencing D and M. No. 3 fencing worked to flooring; some coarse knots, split and wane.

Common lumber; 1 inch thickness:
- No. 1 common boards and strips. Sound, tight-knotted stock, free from large, coarse knots.
- No. 2 common. Admits coarser and larger knots and more stained sap.
- No. 3 common. Admits large, loose, unsound knots; shake, red rot, blue sap stain.

Thick common lumber, 1¼ inches thick and thicker:
- Tank stock. Dimension sizes, free from wane; sound knots and white sap admitted.
- Step plank. 8 inches wide or wider; graded the same as No. 1 common boards.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 427

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 6, 1917

THE POTATO TUBER MOTH.

By J. E. Graf,[1] *Entomological Assistant, Truck Crop and Stored Product Insect Investigations.*

CONTENTS.

	Page.		Page.
Historical	1	Food plants	14
Distribution	2	Life history and habits	15
Possible origin	3	Natural enemies and checks	32
Nature of injury	4	Artificial control	48
Economic importance	6	Summary	51
Classification and synonymy	9	Bibliography	52
Description	9		

The account of the potato tuber moth (*Phthorimaea operculella* Zell.) given in the following pages is the result of an investigation of this insect carried on in southern California from 1912 to 1916.[2]

During the latter part of 1911 the late H. M. Russell conducted a few life-history experiments at Compton, Cal., but the work was not taken up as a special project until the following year. The laboratory work was conducted almost entirely at Whittier and Pasadena, Cal. The material for rearing and collection of parasites, however, was collected from the following counties: Los Angeles, Orange, Riverside, San Bernardino, and Ventura.

HISTORICAL.

The tuber moth was first mentioned in literature by Capt. H. Berthon (1)[3] who described it, under the name of the "potato grub," as being very damaging to potatoes in Tasmania in 1854, and con-

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[1] Resigned Jan. 16, 1916.

[2] The writer wishes to express his indebtedness to Dr. F. H. Chittenden for suggestions throughout the work, and for the use of notes from his files; practically all the data on the occurrence of the tuber moth within the United States outside of California being taken directly from his notes.

Acknowledgment is due Mr. S. S. Rogers, Assistant Plant Pathologist of the University of California Experiment Station, for allowing the writer to collect data relative to the tuber moth in the experiment field at Van Nuys; to Mr. B. L. Boyden of the Bureau of Entomology, who conducted all the rearing experiments from December, 1913, to April, 1914, and to Mr. F. R. Cole for illustrations of the moth in its different stages and parasites, and for assistance in rearing.

[3] Figures in parentheses refer to similar numbers in the "Bibliography," p. 52.

NOTE.—This bulletin is of interest to entomologists and to potato growers especially in the warmer sections of the country.

cluded that it was probably the same insect which had in previous years caused so much trouble in New Zealand.

The tuber moth has been known in California (San Francisco) since 1856,[1] and in southern California at least since 1874.

Mr. William Wood, commissioner of Los Angeles County, reports that in 1874 when planting potatoes in the vicinity of Whittier, Cal., the seed potatoes were badly attacked by the larva of this insect, and in most of the eyes the sprouts had been killed. He states that the Chinese who planted a majority of the fields were in no way worried by the presence of the insect, so he did not consider it a new arrival. The description of the injury given, and the fact that Mr. Wood is quite familiar with this insect, would indicate that the tuber moth was well distributed in southern California before 1874.

The first recognized technical description of the species was made by Zeller (5) in 1873 from specimens collected in Texas. In 1874 the insect was redescribed from specimens collected in Algeria.

An article published by David Gunn (66) mentions the tuber moth as occurring in Canada in 1878. Staudinger and Rebel (39), in their catalogue of Lepidoptera published in 1901, also list this locality. As yet, however, these statements remain unverified, and the tuber moth is not at present known to exist in Canada.

In California the potato tuber moth has been reported as established and working on potatoes in the following counties:

Alameda, Contra Costa, El Dorado, Kern, Los Angeles, Modoc, Monterey, Napa, Orange, Riverside, Sacramento, San Benito, San Bernardino, Santa Clara, Santa Cruz, San Diego, San Joaquin, San Luis Obispo, Shasta, Sonoma,[2] Stanislaus, Ventura, and Yolo.

DISTRIBUTION.

In literature the tuber moth has been given the following distribution, the date appended being either that of the publication, or the time its occurrence was reported.

New Zealand, "Some years before 1854." (1)[3]
Tasmania, 1854 (Capt. H. Berthon). (1)
California (San Francisco), 1856.
Texas, 1872. (4)
Algeria, 1874. (5)
California, 1874.
Australia, 1878 ("Some years back"). (7)
California, 1881. (13)
(Los Gatos, Santa Clara County, 1888). (21)
(Alameda County, 1891). (24)
(Bakersfield, Kern County, 1891). (23)
Florida, 1897. (35)
North Carolina, 1897. (33)
Virginia, 1897. (36)
South Carolina, 1897. (36)
South Africa, 1898. (37)
Hawaii, 1905. (50)
India, 1906. (59)
Southern Europe. (59)
Italy, 1906. (Some years before.) (73)
Cuba, 1907. (54)
France. (88)
Spain. (88)
Canary Islands. (88)
Azores. (88)

[1] California Orchard and Farm, September 15, 1893.
[2] Localities furnished by Mr. E. O. Essig, of the University of California.
[3] Numbers in parentheses refer to similar numbers in the "Bibliography," p. 52.

POSSIBLE ORIGIN.

A study of the literature shows that the tuber moth was known to be present almost simultaneously in Australasia, the United States, and Algeria. It is indeed strange that, considering this fact and, in addition, the fact that this country is the home of a wild potato and tobacco, of all the entomologists who have studied the tuber moth, only one, Gerald McCarthy (31), who found the tuber moth mining tobacco in North Carolina in 1897, should claim that this country is its native home. McCarthy also found the moth in *Solanum carolinense*, a native weed common in the southeastern part of the United States. Speaking of the tuber moth, he says, "This insect probably inhabited its present range prior to the coming of the white man."

Dr. Picard (83, 84), a prominent authority on this insect, says that a Mediterranean origin for this species must be excluded. Considering the fact that he has not found a specific natural enemy, in the shape of a parasite, on the insect, his opinion must be given considerable weight. He mentions either Australia or the United States as a possible origin for the tuber moth.

Analyzing the facts as presented by these two countries, it is seen that it was reported from both places at practically the same time. Edw. Meyrick, one of the earlier authorities on the Microlepidoptera, states that it is not an Australian form. In addition, there is no mention of any natural enemies of the species, which is quite significant, considering that many competent entomologists have worked on it in Australia.

On the other hand, in the United States there are several parasites on the tuber moth, and, as previously stated, this country is the home of a wild potato and tobacco, its two favorite food plants. When it is considered that it was not until the sixteenth century that the potato was introduced into Europe, and that it was not until many years later that the use of the potato became at all general, it seems only reasonable to suppose that the rapid dissemination of the tuber moth came about by following the potato "around the world."

Furthermore, the tuber moth is an insect which could be introduced easily from one locality to another, as once it infests potatoes it is assured of food enough to carry it through several generations; and as the insect can stand lower temperatures than the tubers, it would never be in danger of being killed by freezing.

The entire economic history of the tuber moth is another indication that it originated in America. Losses reported to potato crops in Algeria, India, Tasmania, South Africa, Australia, and New Zealand are far heavier than any ever reported from California or Texas. Climatic conditions being equal, it is generally true that a pest is more injurious in an adopted home, for a time at least, than in its natural one, since the change always favors its being freed from some of its natural enemies and checks. This is especially true of the tuber moth, since most of its parasitic enemies aid in reducing it only when it appears as a leaf miner, and if it were introduced into a new locality in the tubers, these would be left behind.

When all these facts are considered, there is some argument in favor of considering America as its native home.[1]

NATURE OF INJURY.

Injury by the tuber moth is accomplished through two widely differentiated methods of attack: (1) To the growing plant, and (2) to the tuber (fig. 1). The injury to the plant is incident to the mines in the leaf and petiole and to the tunnels in the stem. As a rule the egg is deposited on the leaf, and the larva as soon as hatched starts to mine in the leaf. As the larva grows the leaf becomes too thin for mining, and if there is not another leaf near by to tie up, the larva either rolls the leaf or enters the petiole. If the larva confines its work to the leaves it injures one-third to one-half a leaf during its larval life, but where necessity drives it to mining the petiole it kills the entire leaf. Once started in the petiole the larva rapidly works its way to the main stem, which it begins to tunnel. (Fig. 2.)

The larva generally works downward in the stem, although in a very few cases where the stem is thick and succulent it may turn and work upward. Wherever a larva works within the stem for several days before becoming mature the terminal section of the stem usually dies. It is easy to see that wherever this occurs generally over a field while the potato plants are young considerable injury might result through the reduction of leaf surface and a weakening of the plants.

A factor which would make this possible would be the stacking of a large amount of infested potatoes from the first crop near fields where the second crop of potatoes was just beginning to come up. Only one instance of this type of injury has been noted, although in 1912 conditions were as bad as they would ever be allowed to become.

In one small field (about 7 acres) at least half of the plants were materially injured and the yield was probably reduced one-fourth to one-third. The moths were very abundant in this field at the time the potato plants were coming up, and several could be found on each plant. The reason that more injury was not caused was probably due to the fact that vigorous young potato plants are quick to grow away from any injury.

[1] Notwithstanding the opinions above expressed there are, perhaps, equally good reasons for supposing that this species is of exotic origin, and since it was first reported in New Zealand it would be natural to look to that vicinity for its natural habitat. It has been somewhat generally credited with being native to North Africa, and with reason, since the flora of that continent is particularly rich in solanaceous plants. In fact, the tropical regions of Africa and South and Central America include among their native plants nearly nine hundred species of Solanaceae.—F. H. Chittenden.

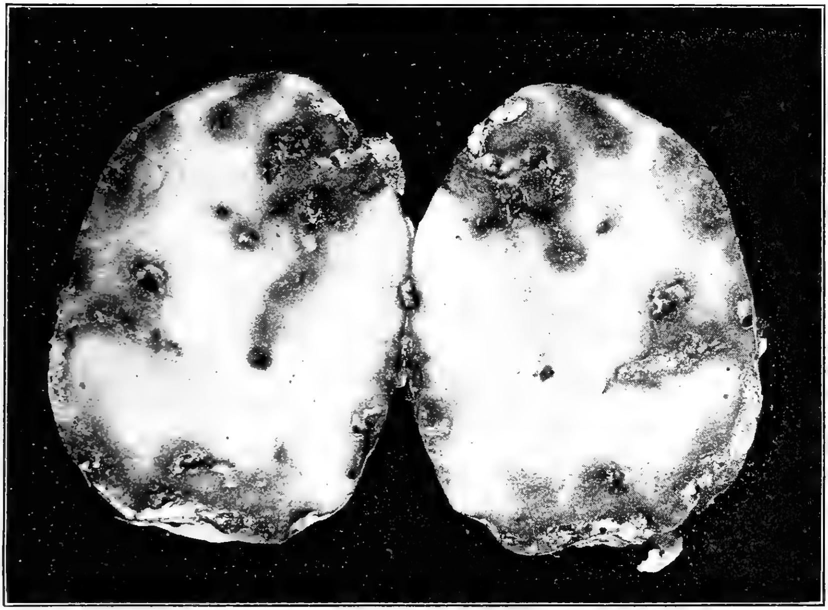


FIG. 1.—Potato section showing injury by larvæ of tuber moth (*Phthorimaea operculella*). (Original.)

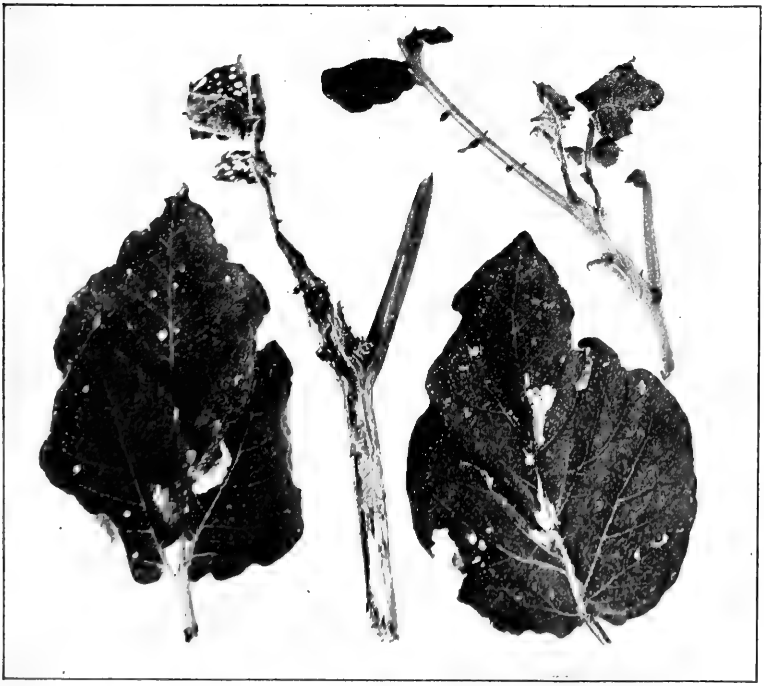


FIG. 2.—Injury by tuber moth to potato plants, showing mines in leaves, petioles, and stem. (Original.)

In large fields near the one mentioned above larvæ could be found in most of the plants, but apparently the vigor of the plants was not noticeably affected and the amount of damage done, if any, was certainly small. Taking all things into consideration, the damage done by the tuber moth to the growing plant in southern California is slight in comparison to that caused to tubers.

The tuber-feeding larva injures the potatoes themselves by tunneling through them, so filling these tunnels with excrement and fungus that the potatoes, even if not severely injured, are very unsightly and of small market value. The character of the injury (figs. 3-5) does not seem to be influenced by the condition of the tuber or climatic condi-

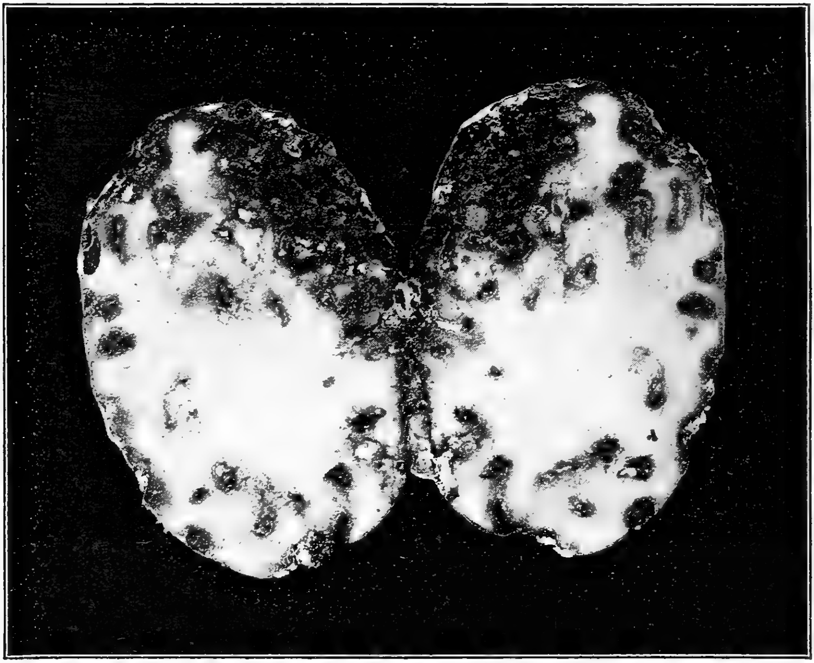


FIG. 3.—Potato sliced to show advanced injury by potato tuber-moth larvæ. (Original.)

tion, some larvæ digging subepidermal channels while others tunnel directly through the substance of the tuber. The loss consists not only of the actual substance of the tuber which is channeled and ruined, but is also due to the fact that badly injured tubers are unsightly and undesirable for food.

ECONOMIC IMPORTANCE.

Since the first report of the tuber moth, large losses have been reported from various sections of the world. Analysis of these reports shows beyond a doubt that in mild, dry climates the tuber moth works very serious injury to stored potatoes. In similar climates,

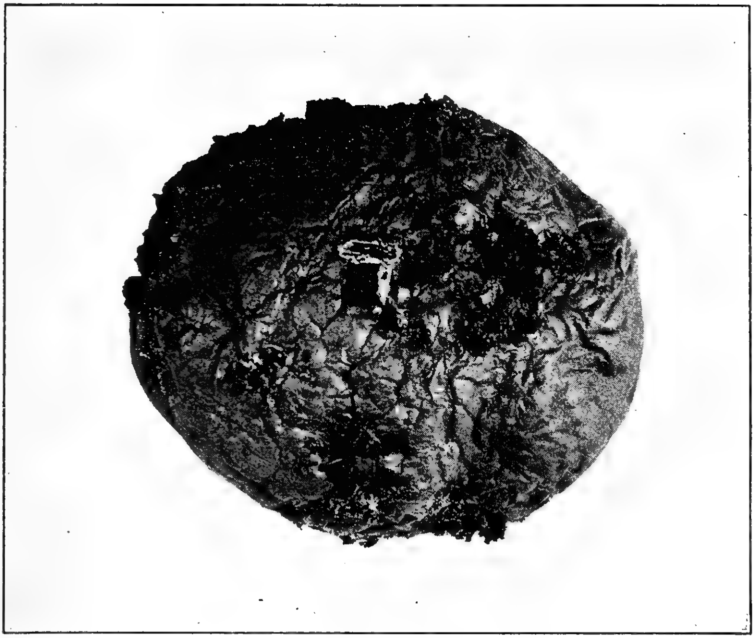


FIG. 4.—Potato in more advanced state of infestation by tuber moth. Larvæ of second generation reared from this tuberpupating. (Original.)

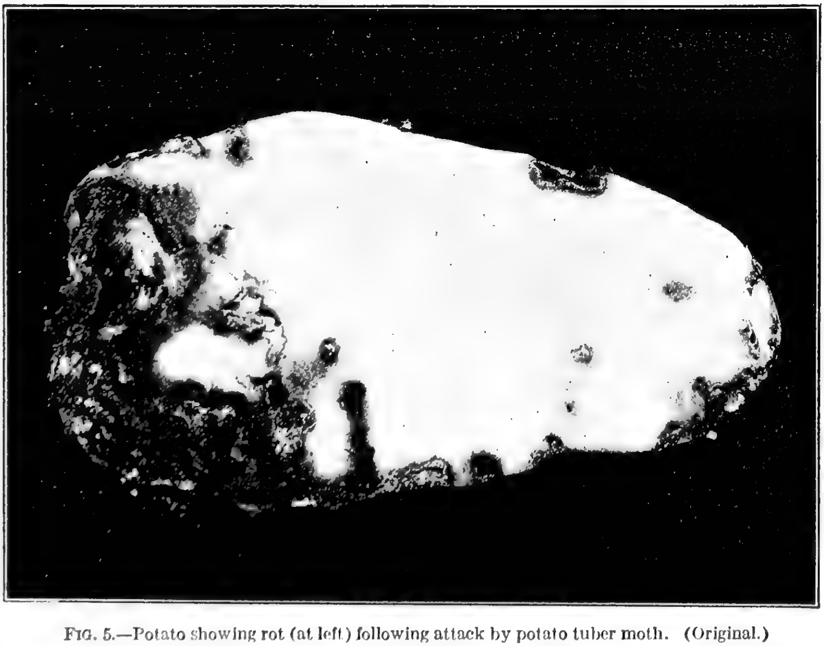


FIG. 5.—Potato showing rot (at left) following attack by potato tuber moth. (Original.)

but where potatoes are not habitually stored, the tuber moth is more in the nature of an annoying pest, causing minor losses practically every year, but becoming of primary importance only where conditions favor its increase. Careless planting, late and slow harvesting, and poor markets with the consequent holding back of the crop, would bring about such conditions.

The tuber moth is reported to have done much injury to potatoes in Tasmania in 1855, and it was then stated that it "has of late years been making ravages amongst tubers in New Zealand" (1).

In 1875 it was reported to have been injurious for the preceding years in Algeria. Specific instances give the losses at El-Bear as three-fourths of the entire crop (6). Meyrick (9) mentions large losses caused by it in Australia in 1878–79, and gives an authenticated case where four-fifths of the crop in one field was destroyed. The tuber moth was reported as destructive to potatoes in California in 1881 and 1882 (13), and in 1901 (37).

In 1897 the tuber moth was noted mining in tobacco in North Carolina (31) and in 1899 was mentioned as being destructive to tobacco and eggplant in Florida (33). In 1898 it was reported from South Africa as being common in potatoes, but, due to the fact that the potatoes were marketed very quickly, seldom causing much damage. Literature further records damage by the tuber moth in India in 1906 (62).

In Australia, India, Tasmania and New Zealand the damaging outbreaks have been of periodic occurrence from the time the tuber moth has been reported. Usually some explanation is given for this condition, and it is noticeable that the outbreaks generally occur during dry years. Authorities seem to agree that the tuber moth is a dangerous pest only to stored potatoes.

This probably explains why the tuber moth attracts so little attention in the United States, where it has long been present. In the warm, dry sections potatoes are never habitually stored, and as these districts supply early potatoes for the neighboring States, under normal conditions the entire crop is harvested as early as possible.

Records of the Los Angeles County Horticultural Commission show that the importation of potatoes is twice as great in the fall as is the exportation in the early summer. This alone shows that normally potatoes once harvested are not held sufficiently long to permit infestation by the moth, or once infested they are used up before their food value is materially impaired thereby. The tuber moth can become of importance only during times of poor market conditions, when the potatoes are held for a rise in price.

CLASSIFICATION AND SYNONYMY.

The tuber moth belongs to that very large and cosmopolitan family of Microlepidoptera, the Gelechiidae. The genus Phthorimaea was founded by Meyrick in 1902 (43), the tuber moth being made the type.

There seems to be not a little difference in the synonymy given this insect by various authors, so the following list has been selected from the literature cited in the bibliography:

Phthorimaea operculella (Zell.) Meyr., 1902	(43)
Gelechia terrella Walk., 1864 [1]	(2)
Gelechia operculella Zell., 1873	(5)
Bryotropha solanella Bdv., 1874	(6)
Lita solanella Meyr., 1879	(9), (11)
Gelechia tabacella Rag., 1879	(10)
Lita tabacella Rag., 1885	(15)
Gelechia solanella Meyr., 1886	(16)

The foregoing synonymy does not take into consideration the *Gelechia similiella* (3) and the *G. solaniella* (4) of V. T. Chambers, which were described in 1872 and 1873, respectively. *G. similiella* was described first and the name subsequently changed to *solaniella* when the larva of this form was found mining in *Solanum carolinense*. Later, in 1878 (8), Chambers adds to his description of *G. solaniella*. Specimens were collected in Kentucky and Texas. It appears from the life notes he adds that the insect in question might be *Phthorimaea operculella*, but there seem to be no types in existence to substantiate this.

DESCRIPTION.

THE EGG.

The egg when freshly laid is opaque, pearly white in color, and with a faint iridescence. As the egg becomes older it becomes yellowish and the iridescence becomes more pronounced, so that at the time of hatching it is nearly lemon-yellow with the iridescence strongly marked. As hatching time approaches the thin shell sometimes becomes more or less distorted, and the outlines of the embryo within can be distinguished. Due to the habit of the moth of ovipositing on rough surfaces, the eggs are often distorted and the shape varies greatly. Two masses of eggs on the surface of a potato are shown in figure 6.

The egg is ellipto-cylindrical in shape, the bluntly rounded ends closely resembling each other. An average of several measurements gave a length of 0.48 mm. and a width of 0.36 mm.

[1] Oldest name, but a homonym.

THE FULL-GROWN LARVA.

The full-grown larvæ (fig. 7, left and right) are slightly fusiform in shape, and plainly constricted at the segments.

The head is dark brown, with the exception of the frons, which is lighter in color. The cervical plate is black, with a pale narrow median line, and the thoracic legs are black. The venter and sides of the abdominal segments are a waxy white and the dorsum is generally a light pink, though in some larvæ there is enough green present to give the dorsum a very light greenish tinge. The spiracles are small, dark, and inconspicuous. There are about 10 to 14 small light hairs on each segment, at the base of each of which there is a small black spot. There are five pairs of prolegs, and near the base of each, on the outside, is a small black projection armed with three stout, short, black hairs. The anal plate varies from a yellow to dusky yellow in color. The full-grown larva is from 9.5 to 11.5 mm. in length, and when fully extended is even slightly longer. At the widest point the average is about 1.5 mm. in width.

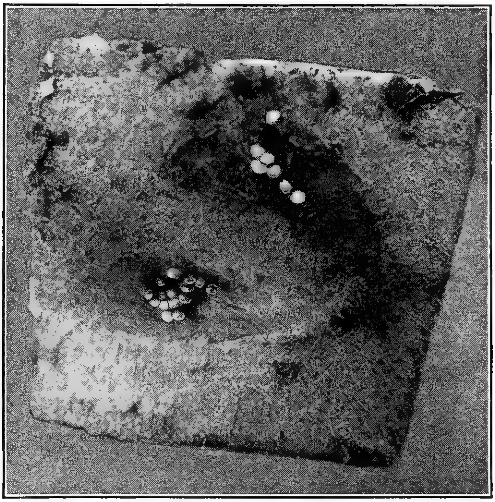


FIG. 6.—Egg masses of the tuber moth on the surface of a potato. Enlarged. (Original.)

As pupation approaches the entire larva becomes greenish in color, and much shorter.

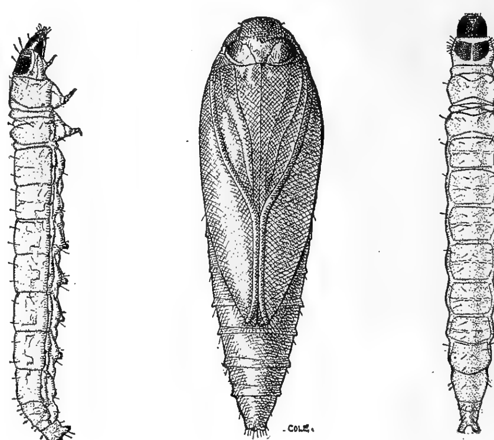


FIG. 7.—The potato tuber moth: Ventral view of larva at left; dorsal view at right; pupa in middle. Larva much enlarged; pupa still more enlarged. (Original.)

THE PUPA.

When first formed the pupa (fig. 7, center; fig. 8) is white, with green markings, but soon changes to deep uniform brown. In general form it is spindle-shaped, being broadly rounded at the head, widest at the thorax, and tapering evenly to the last abdominal segment. The cases for antennæ and legs fold closely on the venter and are rather inconspicuous. The wing cases are also closely folded and generally reach the distal end of the fourth abdominal segment. The tips of the wing cases and the eyes are darker in color. All the segments of the abdomen are armed with a few weak hairs, and the anal segment, aside from its short, stout dorsal hook, bears many light hooked spines arranged in a circle.

THE COCOON.

The cocoon (fig. 9) is white, rather loosely woven, and very thin. The exposed portion is more tightly woven and much thicker, and is

FIG. 8.—Mass of potato tuber-moth pupæ. (Original.)

covered with excrement or débris to such an extent that the white silk of the cocoon is seldom visible. The cocoon is therefore more nearly tectiform than complete and is generally torn in two when the upper part is lifted. As the larva generally seeks some depression in which to pupate, this heavier part is seldom more than half of the entire cocoon and more often less.

The covering of the cocoon is generally composed of particles of the material surrounding it.

THE MOTH.

The moth (figs. 10, 11, 12) is small, having a wing expanse of a little more than a half inch (12 to 16 millimeters). The general color is gray. The forewings bear on the outer half a fringe of light gray as wide at the base as the width of the wing. The surface is more or less spotted and mottled with black and ocher. The hind-wings are much shorter and narrower and have a still stronger fringe of buff.

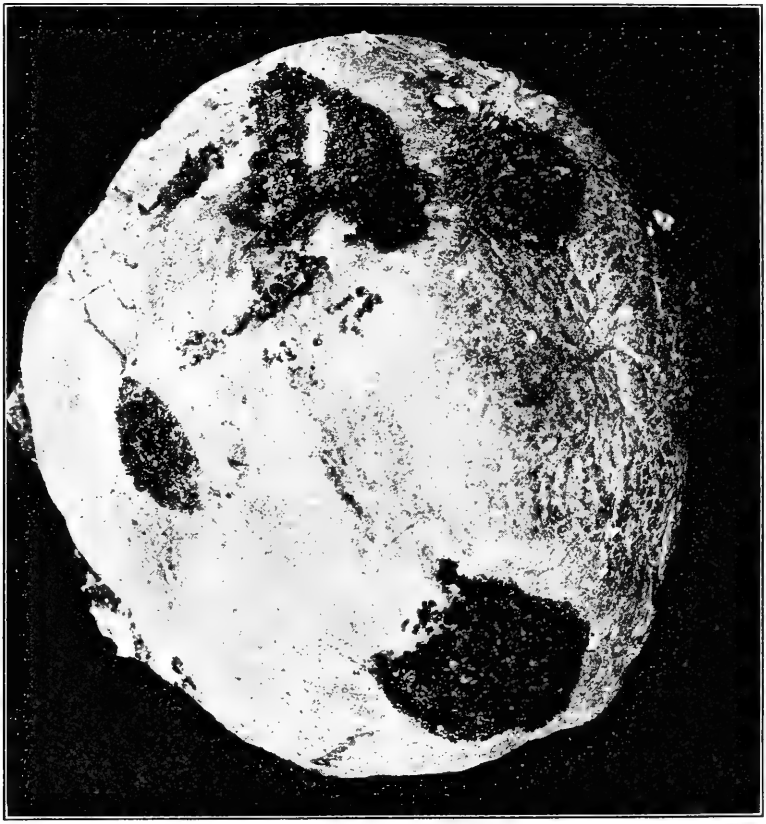


FIG. 9.—Cocoons of tuber moth on exterior of potato, showing method of grouping many cocoons closely under black excrementitious webbing. (Original.)

The antennæ are long and slender and the palpi are comparatively long and conspicuous. The abdomen is also slender.

The following description is a translation of Zeller (5):

> The male bears on the upper side of the anal segment a large oval disk, from each side of which protrudes a readily perceptible tuft of crumpled hair. The somewhat lighter female—if it is the female—has somewhat wider fore-wings, and the dot on the cross-vein and the one before it darker in color, the one toward the inner margin distinctly lighter.

Of the size of the smallest [species] *terella* or of the largest [species] *senectella*. Head whitish, mixed with a little ocherous, brighter on the dorsum. Ocelli I can not perceive. Antennæ gray, lighter on the undersides, with well-defined joints. Palpi whitish, second joint flattened, with noticeably channeled bristles, and having a gray efflorescence on the outer sides near the end. Third joint more than half as long as the second, awl-shaped, finely pointed, with a brown spot between the base and middle. The four front legs light gray, the outsides dusted with brown, tarsi brown, the joints

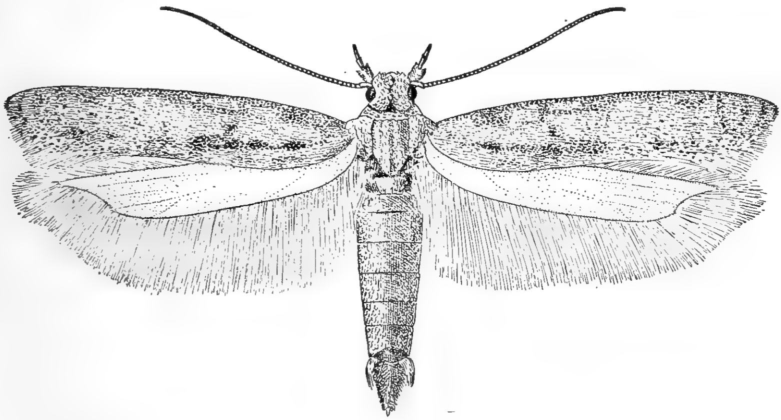


FIG. 10.—The potato tuber moth (*Phthorimaea operculella*). Greatly enlarged. (Original.)

with whitish ends. The hind legs pale yellow, the tibiæ with small light-colored hairs, and the tarsi brownish at the joints. Abdomen yellowish dust-gray, grayish-white beneath, the last joint, in the male, as long as one-third of the abdomen, bright ocher yellow. Two elliptical, somewhat hollowed disks lying with their hollows upon one another. The lower projects somewhat from beneath the upper and is clothed on the upper side with a rich covering of somewhat loose-lying hairs, appressed above and projecting over the margin. On both sides of the base of the upper disk stands an outwardly crumpled brush of hair reaching nearly or quite to the end. In the female the anal joint is of the usual length, and is of the form of a truncated cone, the ovipositor slightly projecting.

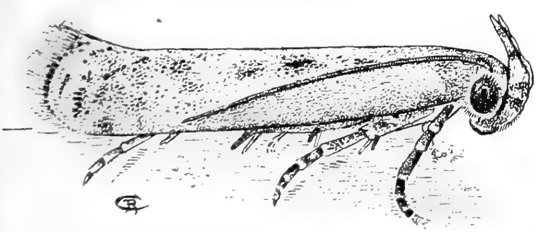


FIG. 11.—The potato tuber moth: Natural position at rest. Much enlarged. (Original.)

Fore-wings $2\frac{1}{4}$ to $2\frac{1}{2}$ ''' in length, smaller in the male than in the female, light gray, dusted yellowish gray, particularly toward the base, in the middle pure ocherous. Along the middle fold lies a longitudinal blackish streak, inclosed at both ends with whitish dashes. Above this lie two small blackish dots, the lower nearer the base than the upper. On the cross-vein is a larger dot, nearly ringed about with light gray. At the rear margin is an indistinct row of blackish, somewhat larger dots. Fringes light gray, inwardly dusted with darker, and especially near the tip.

Hind wings hardly as broad as the fore-wings and with underturned hind fringe, bright gray. Fringe longer than the width of the wing, with a yellowish sheen toward the base. The entire underside uniform gray.

In a doubtful female the whole dorsum is of the same color as the head, the abdomen as before stated. The broader fore-wings are lighter at the front margin, plentifully sprinkled with uniform gray without the usual ocherous color in the middle, and the general ocherous tone of the whole. At the fold lies a black dot with a whitish border. Obliquely behind and over this dot there is no double spot, but a separate stronger deep-black ringlike dot, bright and strikingly inclosed. The cross-vein dot is smaller, but also black and similarly ringed with light color. Since the hind fringes are almost entirely broken off, I can not say further about the markings. The hind wings are sensibly broader than the fore-wings, and less finely pointed.

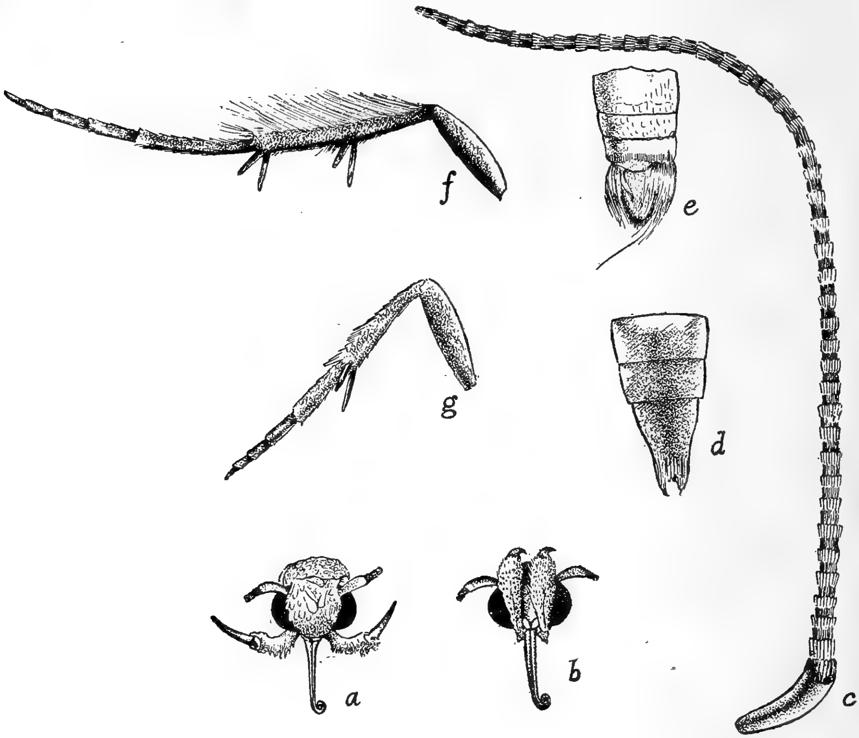


FIG. 12.—Potato tuber moth details: *a*, *b*, Views of the face; *c*, antenna; *d*, tip of abdomen of female; *e*, tip of male abdomen; *f*, hind leg; *g*, foreleg. All much enlarged. (Original.)

FOOD PLANTS.

Prof. F. Picard (83) gives the following food plants for the tuber moth:

- Potato (*Solanum tuberosum*), *S. commersoni*.
- Darwin potato (*Solanum maglia*), Bittersweet (*S. dulcamara*), *S. miniatum*.
- Eggplant (*S. melongena*).
- Tomato (*S. lycopersicum*).
- Red pepper (*Capsicum annuum*).
- Tobacco (*Nicotiana tabacum*), *N. sylvestris*.
- Henbane (*Hyoscyamus albus*), Matrimony vine (*Lycium europaeum*), *Fabiana imbricata*.

To this list may be added nightshade (*Solanum nigrum*), which has been noted as an occasional food plant for tuber-moth larvæ in Southern California.

In the files of the Bureau of Entomology there are also records of this species boring into the stems of poka or Cape gooseberry (*Physalis peruviana*), made by Mr. Jacob Kotinsky in Hawaii. The species has also been found mining the leaves of *Physalis mollis* and *Solanum elaeagnifolium*, at Brownsville, Tex., by Messrs. McMillan and Marsh, of this bureau.

The tuber moth is unable to increase rapidly on plants which confine its activities to mining the leaves, owing to the abundance of its parasitic and predacious enemies. In California, therefore, only the potato, tomato (figs. 13, 14), and eggplant (fig. 15) may be considered as affording suitable protection to the larvæ, and of these, the potato only is of primary importance. While adults have been reared from tomato and eggplant fruit, no important infestations have been noted under field conditions, even where moths were abundant and close at hand.

LIFE HISTORY AND HABITS.

THE EGG.

The egg, under outdoor conditions, is deposited early in the spring on the underside of the foliage of young potato plants. Sometimes the eggs are placed on the stems or petioles of the leaves, but more often the body of the leaf is selected. In such cases the eggs are placed singly, though two or more may be quite close together. Three is the largest number that has been noted on a single leaf in the field.

In bins, or in stacks of potatoes, oviposition takes place throughout the winter, but is most general during the warmer months. The eggs are usually deposited in the eye or a rough scar on the potato, and when placed in this way are generally grouped, as many as 30 having been found in one eye. In sprouting potatoes the eggs are often placed in circles around the base of the sprout. In this way they are protected on all but one side.

Another favorite place for oviposition is at the point of scab injury, and the narrow deep cracks caused in this way are very often filled with the eggs of the tuber moth. Here also they are protected. Where the eggs occur in more or less of a mass, scales from the wings and body of the moth are thinly scattered over them. This probably is not due to an effort of the moth to hide the eggs, but is the result of her moving about during the deposition of the egg mass.

In potato bins eggs are often found on the sacks, in depressions on the sprouts, and on débris occurring on or between the potatoes. However, very small numbers of eggs are found deposited in such places, and they generally occur singly.

The eggs are usually deposited during the evening, night, or early morning, although in cool weather and in darkened bins oviposition takes place at all hours of the day. Daylight oviposition out of doors occurs only on cold and dark days. A single moth under laboratory conditions will deposit 150 to 250 eggs with the extremes of 38

FIG. 13.—The potato tuber moth as a leaf-miner on tomato. An uncommon form of injury. (Original.)

for the minimum and 290 for the maximum; oviposition is completed in from 6 to 17 days, and by far the greater number of eggs is usually deposited in about 4 days.

The largest number obtained in one day from a single female was 68, and this female on two consecutive days deposited 112 eggs.

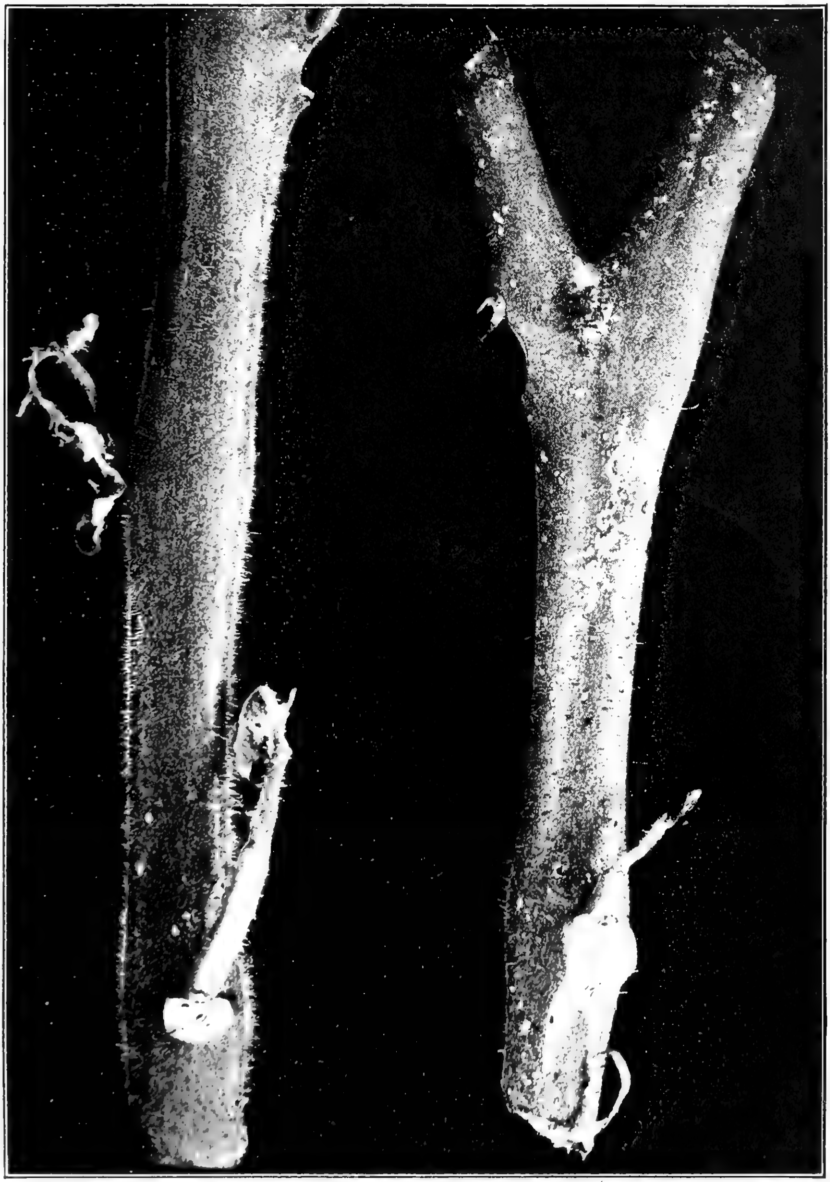


FIG. 14.—Tender stems of tomato killed by potato tuber-moth larvæ. Uncommon form of injury. (Original.)

The length of the egg stage varies with the temperature. Eggs deposited in midwinter may require 34 days to hatch, while those deposited during July and August may hatch in 5 days. There are, naturally, all degrees between these extremes. There seems to be no true hibernation of the egg, those which develop slowly passing through about the same color changes and requiring about the same time in proportion as those which develop very quickly.

There is more or less regularity in hatching of the eggs deposited, even where the period of incubation is the longest. In the case of those which took 34 days, all which were deposited during one night hatched during 36 hours. Practically all the uninjured eggs hatch successfully. From a count kept of those deposited under laboratory conditions only 5 out of 730 eggs failed to hatch; of these 4 were sterile, and the other, after partial development, collapsed.

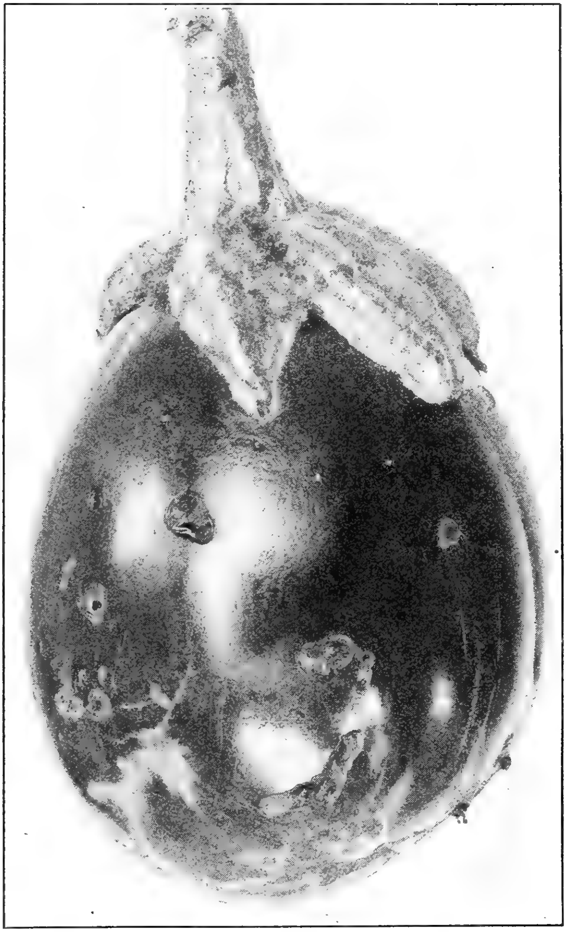


Fig. 15.—Potato tuber-moth injury to exterior of fruit of eggplant. (Original.)

The shells of the eggs, as indicated by the color changes before hatching, are very thin and collapse shortly after the larvæ leave them.

THE LARVA.

EMERGENCE AND FEEDING HABITS.

The larva emerges by eating a hole through the eggshell. The newly hatched larva is about 1 millimeter in length and is quite light in color with the exception of the head, which is dark brown; it is inconspicuous and very difficult to detect when on the surface of a potato.

The larvæ are quite active and begin feeding almost at once. They seldom move far from where they hatch before they begin to burrow. When the egg is laid on a leaf there is slight chance that the larva will migrate to another leaf or to the petiole before starting a mine. In the case of a tuber the larva generally begins where the egg was located, since the irregularity chosen by the moth for oviposition affords a favorable location for starting a tunnel. For this reason the damage to potatoes first becomes evident in the eyes. The fact that the entrance hole is very small and webbed over makes it difficult to detect infestation in potatoes shortly after the eggs have hatched.

After a few days a pink coloration may be detected around the injured eye, and closer examination evidences the presence of excrement held in the web at the entrance to the burrow. The larvæ first burrow straight through the skin and into the substance of the tuber. Some then turn their mines so that they follow close under the skin of the potato. A fungus grows in the burrow and discolors it so that the course of the work may be easily followed. Later the skin of the potato partially dries and sinks so that the scar becomes very prominent; this is commonly called subepidermal injury. This type is the most noticeable, but is not so injurious to the tuber as the deeper channel; and as it dries out more easily, it is not so apt to be the cause of rot.

The channel of the tuber-moth larva is as a general rule deeper and may even go through the center of a large potato. This form of injury is more difficult to detect from the outside than the subepidermal form, but from its greater injury to the potato is the more important. The surface injury may be cut out without much loss to the tuber, but to remove the burrow through the center, the tuber must be cut to pieces and much of it lost.

There seems to be no definite course followed by the larva which might determine the character of injury or the direction taken in the tuber. Some channels are partly subepidermal and partly deep, while other larvæ construct subepidermal channels and still others deep ones.

The channels or galleries generally measure 1 to 3 inches in length and are quite tortuous. The portion occupied by the larva is fresh and white, but the older parts are covered with a matlike brown fungus and often partially filled with excrement. In older injury the mycelium of the fungus may entirely fill the channel. The growth is very compact, and if the tuber is cut in such a way that the injury is exposed the fungus may be lifted out in one piece.

It should be added at this point that, in its occurrence in California, the larva does not prefer to feed upon the tubers in the ground as long as the potato tops are green and succulent. However, as soon as the tops become dry and hard the larvæ do not hesitate to attack the exposed part of a potato, and will even dig through a thin layer of soil in order to reach the buried tubers.

EFFECTS ON THE TUBER.

The immediate effect of the potato-tuber moth on the potato is in the reduction of its market value. This takes place in two ways: (1) By ruining the substance of the part of the potato actually attacked, (2) by causing the entire tuber to be unsightly and, therefore, undesirable. Losses through the tuber moth may practically all be classed under these two heads. It is true that the larvæ cause decay in the tubers; but when this takes place the infestation is generally so heavy and the injury so far advanced that the tubers have ceased to have value, either for food or for seed.

The growing sprouts of seed potatoes also form a favorite point af attack. When thus attacked they are badly injured or killed, and potatoes which have too long been exposed to the attacks of the moth are likely to have their value as seed materially reduced.

NUMBER OF LARVÆ DEVELOPING IN TUBERS.

Since several generations of the insect may develop in a single tuber, it is difficult to determine the maximum that a tuber of average size will support. Mature larvæ have been noted, apparently of normal development, in tubers which contained no appreciable moisture and which were simply a network of pith holding together the dried burrows of previous generations of tuber worms. In one generation 121 pupæ and 3 mature larvæ were taken from a tuber 4 cm. by 6 cm. by 9 cm. The substance of the tuber had been so completely destroyed that on removal from the breeding jar it collapsed.

DEATH OF LARVÆ IN TUBERS.

The normal rate of mortality among the larvæ while tunneling in tubers is very low. Whenever too many develop in a tuber and a putrid condition ensues, very few of the partially developed larvæ escape. Some may leave the tuber and go in search of other food, but most of them remain in the decaying tuber and die.

Larvæ mining in potato tops are very susceptible to change of weather, and in short cold and rainy periods most of the larvæ in the leaves are killed. Those in the stems, being better protected, are safer from weather changes.

LENGTH OF FEEDING PERIOD OF LARVÆ.

The length of the feeding period varies with the temperature. During July and August the active larval life requires as few as 14 days, while during December and January the same period sometimes lasts 69 days. This much greater length of the larval stage in winter is a result simply of retarded development and can not be considered hibernation, as the larva is active and feeding at all times.

METAMORPHOSES.

The instars of the insect show the greatest irregularity, even where conditions as regards food and temperature are kept as nearly uniform as possible. In determining the molting periods, a large number of larvæ, hatched on the same day, were placed on tubers and on each succeeding day the larvæ were dissected from a tuber and preserved in formalin. For the first two days the larvæ were of approximately the same size, but from the time of the first molt the greatest variation was noticeable; when some had reached the last instar others hatched on the same day and feeding on the same tuber were only half grown.

This variation was also very noticeable in the life-history work. Where the first mature larvæ appeared in 18 days, there were mature larvæ leaving the tuber for the succeeding 6 days. Table 1 shows the variation in the length of the larval period with larvæ from the same egg masses.

TABLE 1.—*Length of larval stage of the potato tuber moth with larvæ from the same egg masses.*

Eggs hatched.	Number of mature larvæ.	Dates between which they appeared.	Number of days in emergence period.
1913.			
Nov. 5	41	Dec. 16 and Jan. 4	19
Dec. 3	8	Feb. 3 and Feb. 21	18
1914.			
Jan. 2	7	Mar. 2 and Mar. 28	26
Feb. 2	11	Mar. 16 and Apr. 4	19
Mar. 19	67	Apr. 21 and May 2	12
Apr. 1	23	May 1 and May 12	11
May 4	18	June 2 and June 10	8
June 19	47	July 6 and July 14	8
July 5	20	July 21 and July 27	6
Aug. 4	38	Aug. 18 and Aug. 23	5
Sept. 1	44	Sept. 21 and Sept. 30	9
Oct. 4	19	Nov. 3 and Nov. 16	13

As has been suggested, the rapidity of growth of the larva seems not to be influenced by the amount of food. Larvæ developing in leaves, stems, or petioles, grew more rapidly than those in the tubers. In these experiments the larvæ were kept on potted plants indoors, and those in tubers were placed in a breeding jar beside the plant. The experiments were carried on under the same temperature, but the larvæ in the leaves were more exposed to changes in temperature, and whether the greatest difference in the time of development was caused by a variation in temperature or a difference in the character of the food, it would be hard to determine. It seems probable, however, that the larvæ in the potato tops had the most succulent food, and that this made some difference in the time of development. The results of the experiments are shown in Table 2.

TABLE 2.—*Length of larval stage of potato tuber moth; comparison of larvæ reared on tubers and larvæ reared on potato tops.*

LARVÆ REARED ON TUBERS.

Eggs hatched.	Larvæ mature.	Larval stage.
		Days.
Nov. 10, 1915	Dec. 13	33
July 5, 1914	July 14	16

LARVÆ REARED ON POTATO TOPS.

Eggs hatched.	Larvæ mature.	Larval stage.
Nov. 10, 1915	Dec. 7	27
July 5, 1914	July 18	13

The process of molting is similar to that in other lepidopterous larvæ, the skin splitting down the dorsum of the first few segments, and the larva working its way out through this opening. By far the greater time is taken up in preparation for molting and in resting after the operation.

LEAVING THE TUBER.

When the larvæ become mature they usually leave the tuber for pupation. If they remain in their channels they come out toward the opening, so that the head of the pupa is just under the skin of the potato. When the larvæ leave the tuber they are very active and seldom remain exposed very long. If they are disturbed in any way they throw themselves about until they reach shelter of some kind. They are especially active when parasites are near, and should the latter approach, contort themselves rapidly until the parasite has disappeared.

When a suitable place for pupation is discovered, an operation which may consume from an hour to a day, the larva begins a cocoon at once, working so rapidly that very soon it is covered with a thin mesh. If disturbed, it will often leave its partially completed cocoon and seek another place to pupate. Sometimes one larva will interfere with another spinning a cocoon to such an extent that the partially constructed cocoon will be deserted by both. Parasites, however, cause the desertion of the greatest number of cocoons by attempting oviposition before the cocoon is completed.

Cocoons containing pupæ of the tuber moth were noted in an old bin in the following places: (1) In the eyes of potatoes; (2) between potatoes (where they touched or almost touched); (3) between potatoes and bin walls; (4) between potatoes and sacks; (5) in folds of sacks; (6) in cracks in bin walls; (7) in nail holes of bin walls; (8) on bin walls; (9) in rubbish on floor; (10) on open floor (mostly naked); (11) in end of burrow with cocoon partly protruding; (12) in old burrows under dry skin of potatoes.

In the field, where the larvæ were working on potato tops, the pupæ were noted in the following places: (1) In curled dried leaves on the plant; (2) under clods and rubbish, and (3) protruding from old burrows in the stem.

Under field conditions most of the pupæ were found in the dried leaves which still clung to the potato plant.

After the larva has completed its cocoon it spends a period varying from two days to a week or more before changing to the pupa. The larva becomes greenish all over and sometimes takes on a faint blue tinge. It also becomes much shortened and constricted at the segments, and loses nearly all its activity. This stage varies very much with the temperature, being much shorter in summer than in winter. The larva is helpless at this time and can not move within its cocoon sufficiently to ward off the attacks of parasitic enemies. During this period the greatest amount of parasitism of the mature larva takes places.

THE PUPA.

As the time of pupation approaches, the skin on the dorsum of the anterior segments of the larva splits, and the pupa works the skin off in a short time. The cast skin occupies a small space in the posterior end of the cocoon.

The pupa when newly formed is white with greenish markings. It soon begins to darken and in a few hours' time is uniformly dark brown. When first formed it remains quiet until it becomes hardened, but is very sensitive and if disturbed turns itself around by moving the tip of its abdomen in a circle. The hooks at the tip of the abdomen are sometimes fastened in the cocoon, so that even if part of the anterior end of the cocoon is torn off, the pupa will not necessarily be dislodged. Just before emergence it is quite active and turns itself around quickly if disturbed. As the time for emergence approaches the pupa becomes still darker in color and is less active.

The period of pupation varies greatly with the temperature and even when under constant temperature. Lots of pupæ formed on the same day vary to such an extent that the last to emerge often requires twice as long as the first. Experiments undertaken to determine the influence of sex on the length of the pupal period gave entirely negative results, as both sexes were practically evenly divided at all periods of emergence.

Extreme variations for the pupal period indicated 8 days for July and 56 days for December and January. Variations during one month include 12 days for the shortest and 29 days for the longest period.

Even where the pupal stage is of the longest duration the ratio of this to the increased length of the other stages of the moth remains so nearly constant that it seems development within the pupa must continue all the time, though, of course, at a greatly reduced rate. For this reason this longer pupal stage must be classed as retarded development and could hardly be termed true hibernation.

THE ADULT.

EMERGENCE.

The skin of the pupa splits along the dorsum of the thorax, and the moth by contracting itself draws its head from the pupal case. From this time on it is never quiet, contracting and expanding its abdomen and withdrawing its legs from their cases on the venter of the pupa. When the legs are free and the body has started to move in the case, the whole insect is free within a few moments. The freshly emerged adult generally moves very little until it has expanded its wings to their normal size. Sometimes the latter process is quite slow, but generally within a short time the wings reach beyond the tip of the abdomen. Even after development is apparently complete the moth prefers not to attempt flight for some time, but if disturbed either feigns death or seeks a place of concealment with a characteristic jerky running movement.

For some time after emergence the adult spends most of the time in hiding, but if sweetened water is placed near it the insect will feed readily.

HABITS OF THE MOTH.

Under field conditions the habits of the insect are well adapted to protect it until the eggs are deposited. During the day the adult hides beneath rubbish, or if the fields are clean, under clods of earth. Its coloring is very protective, and it is difficult to locate the adults even after they have been observed to alight. They seldom fly in the field during the brighter hours of midday, unless disturbed, and then the flight is short and jerky, and on alighting they seek concealment. When they fly to the potato vines they hide beneath the leaves, so that they are seen with difficulty. Under field conditions they have not been noted to take food. The activity increases with the temperature, being greatest during warm nights.

PROPORTION OF THE SEXES.

The proportion of the sexes during the year remains very nearly constant and almost equal. Pupæ selected at random at various times of the year gave the results shown in Table 3.

TABLE 3.—*Proportion of sexes of the potato tuber moth.*

Month.	Number of pupæ.	Male.	Female.	Not emerging.
January	127	69	51	7
April	200	111	86	3
July	200	95	104	1
October	100	52	43	5

REPRODUCTION.

Mating takes place within a day or two after emergence. During the summer months this time may even be reduced. Sexual attraction is quite strong, the males being readily attracted to the females. Pairs may mate several times, frequently promiscuously. Mating is most common during the morning and evening. Mating pairs have been noted in the field, generally under clods and rubbish, at temperatures of from 59° to 65° F.

Oviposition takes place within from 24 to 48 hours after mating. Generally only a few eggs are deposited the first night, from 10 to 20 in number. The maximum number is deposited the second, third, and fourth nights. Oviposition by a female when fed on sweetened water may last for two weeks, but even in these cases it will be found that over half of the eggs were deposited before the fifth night.

The following record gives the oviposition record of an average pair:

October 7.—Pair mating.
October 8.—7 eggs deposited.
October 9.—31 eggs deposited.
October 11.—57 eggs deposited.
October 12.—39 eggs deposited.
October 14.—34 eggs deposited.
October 15.—5 eggs deposited.
October 17.—11 eggs deposited.
October 18.—3 eggs deposited.
October 19.—0 eggs deposited.
October 22.—Female dead.

Oviposition takes place almost altogether at night, especially during warm nights. On cool dark days eggs are sometimes deposited, but these are few in number and very seldom are two found placed together. When the moths are kept in darkened cages they deposit a few eggs during the day, but even here the greater part of oviposition takes place at night.

Adults in the act of ovipositing on potatoes were very commonly noted. The female generally sought the eye of the potato and after turning around a few times settled down and remained quiet for a few moments. Just before oviposition the tip of the abdomen was moved around slightly until a suitable place was found, then the abdomen was contracted rapidly by drawing in the tip and the egg was extruded.

The egg when first deposited is viscid, and translucent white, but hardens in a very short time. Generally the adult moves about after oviposition until another satisfactory place is found, but the same adult may deposit most of a night's quotum of eggs in the same place. In case the adult discovers a narrow deep crack in the tuber the eggs are often placed within it in a chain. When the breeding jars are covered with cheesecloth it is always found that some eggs are deposited on the cloth. This is in corroboration of the fact stated by Picard (83), that oviposition is stimulated by a roughened surface.

RELATION OF FOOD TO OVIPOSITION.

Experiments to test the effect of feeding on oviposition show that both the period of oviposition and the number of eggs laid may be increased by feeding. In these experiments some of the moths were kept in dry vials, some in vials with a little water, and others in vials with sugar water. Those kept with water were under conditions more like those outdoors, while the ones in dry vials would be under extreme laboratory conditions.

The results are shown in Table 4.

TABLE 4.—*Relation of food to oviposition of the potato tuber moth.*

Nature of experiment.	Number of adults.	Total eggs deposited.	Average number of eggs per female.
Without food	10	1,138	114
Water	10	1,472	147
Sweetened water	10	2,094	209

Temperature also has a very important effect, not only on the rapidity with which eggs are laid, but on the number as well. During the winter months, when the nights become cool, very few eggs are deposited by an adult, and these are well scattered. The period of oviposition is longer during a season of cool nights, but even this does not make up for the fewer eggs laid, as will be seen in Table 5.

TABLE 5.—*Effects of temperature on oviposition of the potato tuber moth.*

Pair of adults mating.	Oviposition period.	Total eggs laid.
	Days.	
January	17	109
April	14	247
June	8	262
August	9	294
November	13	142

September and October also showed large egg records, 27 out of 35 adults under observation depositing over 200 eggs each.

EFFECT OF FERTILITY ON OVIPOSITION.

Unfertilized females were isolated at different seasons of the year to test the effect on oviposition. Almost all of these deposited eggs at some time during their lives, but the eggs were deposited irregularly and in much smaller numbers.

Table 6 shows some of the greatest variations to be found in this connection.

TABLE 6.—*Oviposition of the potato tuber moth by virgin females.*

Female No.	Period between emergence and oviposition.	Total number eggs.	Period of oviposition.	Length of life.
	Days.		*Days.*	*Days.*
1	5	13	7	17
2	1	51	1	2
3	3	6	5	13
4	7	44	9	22
5	4	1	1	11
6	5	18	16	21
7	5	29	13	18
8	4	9	6	12
9	....	0	....	28
10	6	32	10	17

Examination of this table will show also that oviposition was delayed longer after emergence than in the case of fertilized females.

POSSIBLE PARTHENOGENESIS.

To corroborate the observations on parthenogenesis cited by Picard regarding this insect (83), unfertilized females were isolated during spring and fall, and all the eggs deposited were carefully watched. In these experiments 54 females deposited a total of 486 eggs, of which 324 were laid during September and 162 during April and May. None of the eggs hatched, showing that while parthenogenesis may exist, it is not very common.

LENGTH OF LIFE.

Pairs of adults isolated proved that the length of life of the male is shorter than that of the female. This proved to be the case in 221 out of 275 experiments carried out for egg records. In nearly every case where the female died first the egg record was poor, indicating that the female was abnormal to begin with. The length of life varies with the temperature, the warmest season giving the shortest life records. This is even more pronounced where the adults are not fed.

The extremes noted for length of life were, for the male 1 to 14 days, and for the female 2 to 22 days, in cases where the pairs had mated. In experiments using unmated individuals the length of life for the male varied from 3 to 31 days, and for the female, 2 to 28 days.

In the case of the male which lived 31 days no food was given, and the individual was kept in a dry vial. This record was made during November when the weather was cool.

A fairly average record of a pair of adults which mated October 29, 1914, is as follows:

October 31.—40 eggs.
November 1.—63 eggs.
November 2.—28 eggs.
November 4.—41 eggs.
November 5.—18 eggs.
November 8.—19 eggs. Male dead.
November 10.—6 eggs.
November 12.—3 eggs.
November 13.—0 eggs. Female dead.

SEASONAL HISTORY.

NUMBER OF GENERATIONS.

The number of generations in one year, as might be expected, is subject to the wide irregularity shown in the separate stages, and to temperature and other natural influences.

By taking the first to emerge from each brood, six generations are theoretically possible. In reality this would include five complete generations, and the beginning of the sixth.

By starting several generations in each month for almost three years, it was possible to determine the average length of generations for the different months of the year.

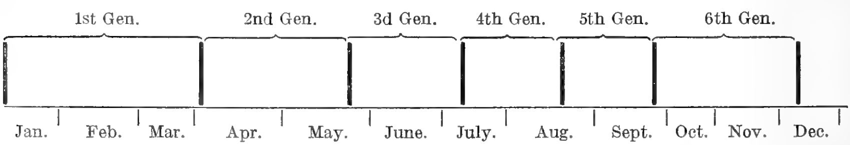
Table 7 gives the results obtained:

TABLE 7.—*Length of generations of the potato tuber moth.*

Month of starting generation.	Approximate length of generation.	Month of starting generation.	Approximate length of generation.	Month of starting generation.	Approximate length of generation.
	Days.		*Days.*		*Days.*
January	90	May	50	September	45
February	75	June	40	October	70–75
March	65	July	30–35	November	92
April	55	August	30–35	December	95

Consecutive generations for a year, using the first to emerge, may be plotted as follows:

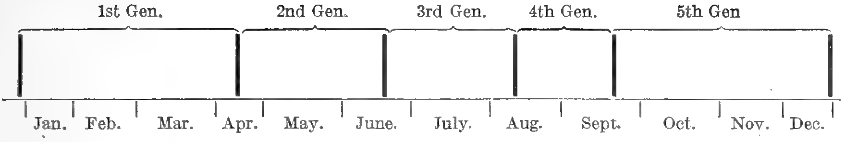
Plot A.



This shows plainly that even in the more severe years six generations may be obtained, using the first to emerge from each brood.

By using the last to emerge from each brood, the number of generations is reduced as the following plot shows.

Plot B.



The gradual emergence of adults from a generation the larvæ of which all hatched on the same day may be shown from the examples which follow, one from midsummer and the other from midwinter.

TABLE 8.—*Emergence of adults of the potato tuber moth from two generations, the eggs of one hatching on July 7 and those of the other on December 8.*

Average mean temperature 72° F.	Average mean temperature 51° F.
1914	1914
July 7. Eggs hatched.	Dec. 8. Eggs hatched.
	1915
Aug. 1. 2 adults emerged.	Mar. 7. 2 adults emerged.
Aug. 3. 21 adults emerged.	Mar. 9. 4 adults emerged.
Aug. 5. 18 adults emerged.	Mar. 10. 2 adults emerged.
Aug. 6. 4 adults emerged.	Mar. 11. 1 adult emerged.
Aug. 8. 1 adult emerged.	Mar. 12. 6 adults emerged.
Aug. 10. 2 adults emerged.	Mar. 13. 3 adults emerged.
Aug. 11. 0 adults emerged.	Mar. 14. 3 adults emerged.
	Mar. 16. 1 adult emerged.
	Mar. 18. 4 adults emerged.
	Mar. 20. 1 adult emerged.
	Mar. 23. 1 adult emerged.
	Mar. 30. 0 adults emerged.

The records given above show plainly the difference in number of generations which may be caused by taking the first to emerge or the last to emerge in each life cycle. If the first eggs deposited by the "first to emerge," and the last eggs deposited by the "last to emerge" are taken for the second generations, the difference will be increased to such a degree that almost a month will elapse between the time of starting the two generations.

Taking generations throughout the year gives the following periods (Table 9). The records are for 1914, and were made at Pasadena, Cal.

TABLE 9.—*Variation in life cycle of the potato tuber moth.*

Month started.	Eggs laid.	Adults emerging.		Greatest number emerging.	Length of life cycle.
		First.	Last.		
1914.					*Days.*
January	Jan. 4	Apr. 6	Apr. 30	Apr. 10	91
February	Feb. 11	Apr. 25	May 13	Apr. 29	73
March	Mar. 18	May 18	May 31	May 21	61
April	Apr. 15	June 9	June 20	June 12	55
May	May 16	July 4	July 16	July 7	49
June	June 14	July 24	Aug. 3	July 27	40
July	July 13	Aug. 15	Aug. 23	Aug. 17	33
August	Aug. 17	Sept. 19	Sept. 27	Sept. 22	33
September	Sept. 14	Oct. 29	Nov. 10	Nov. 1	45
1913.					
October	Oct. 14	Dec. 24	Jan. 14	Dec. 31	71
November	Nov. 7	Feb. 7	Feb. 22	Jan. 13	92
December	Dec. 12	Mar. 19	Apr. 10	Mar. 25	97

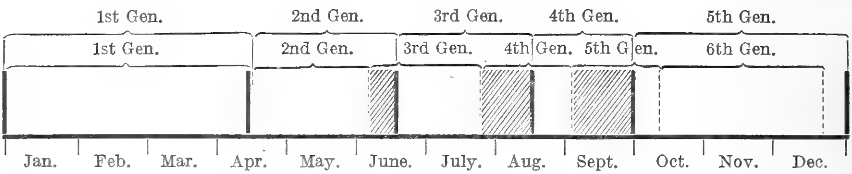
In examining this table it must be borne in mind that the results given are for a particular year, and great variations are possible from similar months in other years. One example will be sufficient to illustrate this point: During the middle of April, 1914, the mean temperature averaged about 66°, and during this time eggs of the tuber moth were hatching in from 8 to 9 days. During the same period of 1915, with the average mean temperature about 59° F., the egg stage lasted from 12 to 14 days. All stages of the insect vary so greatly that it is difficult to foretell how long a generation will take.

OVERLAPPING OF GENERATIONS.

From the foregoing examples it is evident that all stages of the tuber moth exist throughout the year in Southern California, and consequently the broods can not be distinguished. Many writers have estimated the numbers of broods or generations by the abundance of moths at different times of the year. If conditions are considered, it may be seen that food and temperature govern this condition. In summer, with an abundant food supply, the insect multiplies with great rapidity, adults become abundant, and the impression of the emergence of a brood is given. If plots A (p. 28) and B (p. 29) are compared, the overlapping of generations may be understood.

By placing one over the other as in plot C, the shaded areas show the time adults are emerging. The broken lines are from plot B.

Plot C.



This diagram indicates that although the generations may secure an even start at the beginning of the year, by late summer and fall the first to emerge from the fifth generation are appearing at a time when there are still adults from the fourth generation emerging. This explains the presence of all stages of the insect at all times of the year, and indicates that from the economic side a knowledge of the life history of the moth is of little importance, except as it shows the possibilities of reproduction.

HIBERNATION.

During the discussion of the effect of temperature on the various stages of the tuber moth the impression was given that there is no hibernation for any length of time in southern California. This is surely the case under normal conditions, though possibly there is no noticeable development for a few days at a time when the average mean temperature is low.

Experiments were carried on in the storage rooms of an ice company at Pasadena to determine if low temperature acting for some time would kill the various stages of the moth or whether they could hibernate successfully. For these experiments the following stages were taken: Adults, pupæ, mature larvæ in cocoons, and eggs. Two experiments were carried on at the same time. One lot was kept at 32° F. for three weeks, while the other lot was kept for 35 days at a temperature of 38°–40° F.

The results are summarized in Table 10:

TABLE 10.—*Effect of low temperatures on stages of the potato tuber moth.*

Time.	Temperature (constant).	Adults.	Pupæ.	Mature larvæ.	Eggs.
21 days	32° F.	Most alive and active	Alive	Alive	Alive.
35 days	40° F.	Over half were dead	...do	...do	Do.

In the cases where the various stages were alive they developed normally when taken from storage. In both experiments development was stopped in all stages while the material was in storage. These results show that the tuber moth may hibernate successfully where conditions demand it and that no development takes place below 40° F. Prof. Picard (83) says that no development takes place below 50° F.

DISSEMINATION.

The tuber moth is disseminated by two means, natural and artificial. Of these two the former (by flight of the moth) is much the slower and, as it can hardly be controlled, is relatively unimportant. The most important spread of the tuber moth takes place through the movement of infested potato tubers. In this way the insect is assured of an abundance of food, and since the tubers are not allowed to freeze, the temperature is always favorable. In interstate and international shipments the moth is given every opportunity to spread and has probably been introduced at some time into every civilized country on the globe.

It is even possible that a careful inspection will show that it is established in many localities where it is now unknown. This is especially likely to be the case in districts where the climate is cold and wet and therefore unfavorable for the insect's normal development.

MORTALITY OF THE STAGES.

The mortality in the various stages must be considered from the standpoint of whether the insect is working on potato tops or on stored potatoes. Under field conditions as a leaf miner the mortality is so high that an increase of the insect from this source is highly improbable. Rains and sudden changes in climatic conditions kill many of the larvæ, and the large number of predacious and parasitic enemies further reduce the numbers of the insect. The figures will be considered later with the discussion of natural enemies.

When the insect attacks stored tubers the percentage of insects developing safely is very high. Figures show that practically all the eggs deposited hatch. In storage there is always an abundance of food and all stages are protected from most of their enemies, so most of the larvæ develop successfully.

POSSIBLE RATE OF INCREASE.

The theoretical rate of increase for the tuber moth is very rapid. Taking 150 as the average number of eggs deposited and counting half the adults as females, the progeny of one pair would give about 60,000,000 adults at the end of the fourth generation.

While this theoretical rate is seldom even approached, it serves to show that under favorable conditions for reproduction the insect may increase to damaging numbers in a short time.

NATURAL ENEMIES AND CHECKS.

Where the tuber moth works as a leaf-miner on the potato tops, its numbers are kept down very well by its enemies and climatic changes. Its numerous parasitic enemies play the most important part, rains and cold weather probably come second in point of importance, and the predacious enemies last.

In southern California the parasitic enemies of the tuber moth form a fine series and work on every stage. The egg and pupa each has its parasite, while several attack the partially grown larvæ and at least two the mature larvæ.

Only three of these work on the tuber worm infesting potatoes, and here they are only partially effective. The burrowing habit of the larva protects it from parasites except while spinning its cocoon and pupating. Parasites are also hampered by the storage of potatoes. Altogether it is doubtful if parasites could be of practical importance when the insect infests stored tubers. Certainly the stored potatoes examined have discouraged such a belief.

Experiments to ascertain the percentage of parasitism in the potato tops show that the parasites, taken altogether, are valuable in the control of the tuber moth. The impracticability of direct methods of control necessitates the use of all possible measures to limit the number of moths before harvest. This is well accomplished by the parasites, resulting in lessened injury to the leaf surface and diminishing the number present to infest the potatoes just before and during harvest.

PARASITES.

Parasites vary in effectiveness. During 1914 *Habrobracon johannseni* (fig. 16) was the most effective, and the following list probably gives them in the order of their importance for that year:

Habrobracon johannseni Vier.
Chelonus shoshoneanorum Vier.
Sympiesis stigmatipennis Girault.
Campoplex phthorimaeae Cushm.
Bassus gibbosus Say.
Apantales sp. (Chttn. No. 2230^{07}).
Microgaster sp. (Chttn. No. 2230^{08}).
Nepeira benevola var. *fuscifemora* Cushm.
Zagrammosoma flavolineatum Cwfd.

During early 1915 *Dibrachys clisiocampae* Fitch was discovered, and while not so well distributed, it seems to be well fitted to be an

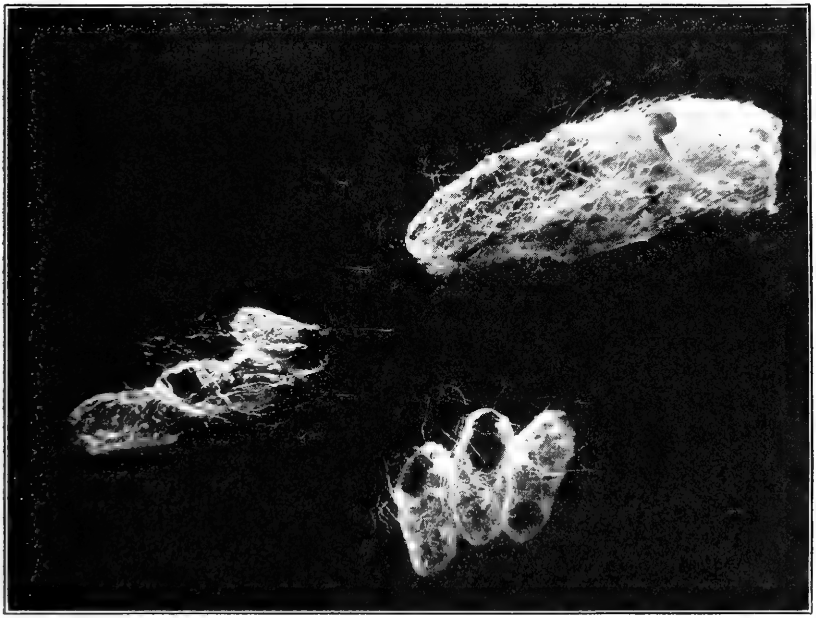


FIG. 16.—Empty cocoon of the potato tuber moth (large one) and cocoons of its parasite, *Habrobracon johannseni.* Much enlarged. (Original.)

effective enemy. Ranking the parasites in the order of their importance for 1915 would give them the following order:

Dibrachys clisiocampae, *Sympiesis stigmatipennis*, *Campoplex phthorimaeae* } Of about equal importance.
Apanteles sp. (Chttn. No. 2230^{07}).
Habrobracon johannseni.
Chelonus shoshoneanorum.
Bassus gibbosus.
Microgaster sp.
Nepeira benevola var. *fuscifemora.*
Zagrammosoma flavolineatum.

The last four species in each list were relatively unimportant during both years in the districts from which material was collected for study. These were as easily reared in confinement as most of the others, and there seems to be no reason why they should not be important equally with other species which oviposit in the tuber larva where it occurs as a leaf-miner.

DIBRACHYS BOUCHEANUS RATZ.[1]

This well-known and cosmopolitan secondary parasite (fig. 17) emerged from the tuber-moth material collected during 1912, 1913, and 1914, and, as shown by dissection, from both *Habrobracon*

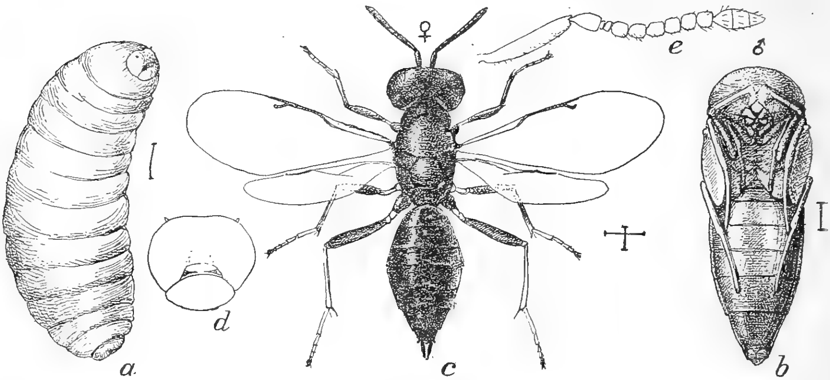


FIG. 17.—*Dibrachys boucheanus: a,* Larva; *b,* pupa; *c,* adult female; *d,* head of larva; *e,* antenna of male, highly magnified. Greatly enlarged. (After Howard.)

johannseni and *Chelonus shoshoneanorum,* the former seeming to be its favorite host. This species was reared from the egg in the laboratory, where it attacked the mature larvæ of its hosts after they had spun their cocoons. Where the cocoons were not too thick to prevent it from reaching its host the parasite would often feed at the wounds caused by its ovipositor.

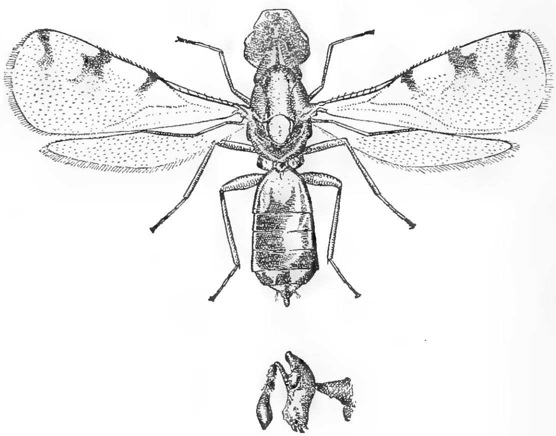


FIG. 18.—*Zagrammosoma flavolineatum:* Adult male, with lateral view of head. Much enlarged. (Original.)

When reared under laboratory conditions the hyperparasites increase rapidly, but under field conditions their numbers are not as large in proportion to the host as might be expected. During 1912 and 1913 the percentage of parasitism ran as high as 50 per cent in the case of *Habrobracon johannseni.* With *Chelonus shoshoneanorum* the average was much lower, the highest running 29 per cent. During 1914 the percentages in both cases were much reduced, and while greater numbers of its two hosts were reared than in the previous year, *Dibrachys boucheanus* was noted on only a few occasions.

[1] Chittenden No. 2230°°.

During 1915 the parasitism averaged slightly over 1 per cent, as two individuals of *Dibrachys boucheanus* were reared, while 172 specimens of *Habrobracon johannseni* issued in the parasite cages.

Three or four specimens were commonly noted in one host, and in the material reared under laboratory conditions a single hyperparasite was rarely reared from one host.

The following record shows the development of a fall generation:

1913.
October 27.—*D. boucheanus* parasitizing mature larvæ of *H. johannseni.*
November 8.—*D. boucheanus* larvæ mature.
November 14.—*D. boucheanus* larvæ pupating.
December 7.—2 *D. boucheanus* adults issued.
December 8.—7 *D. boucheanus* adults issued.
December 10.—4 *D. boucheanus* adults issued.
December 11.—1 *D. boucheanus* adult issued.
Life cycle 40 days at average mean temperature of 62° F.

ZAGRAMMOSOMA FLAVOLINEATUM CWFD.[1]

During 1914 and 1915 *Zagrammosoma flavolineatum* (figs. 18, 19) was noticed issuing from cages containing some *Phthorimaea operculella*

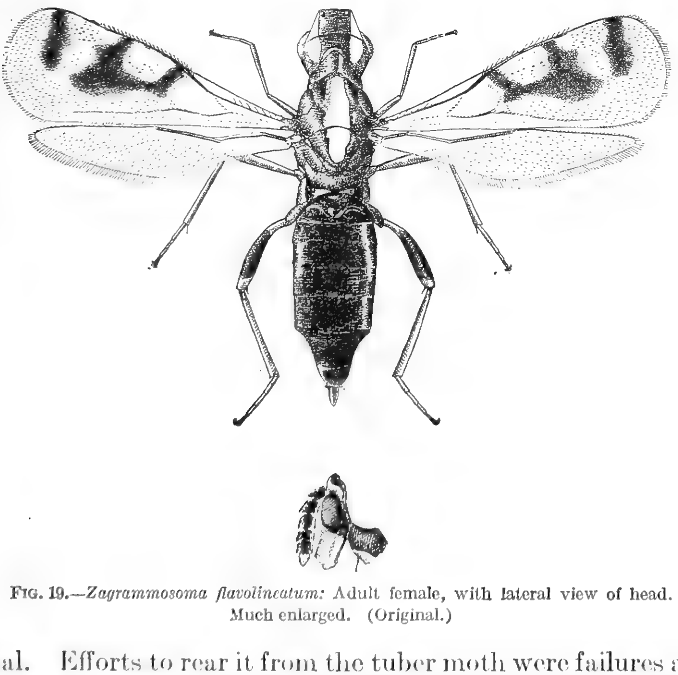


FIG. 19.—*Zagrammosoma flavolineatum:* Adult female, with lateral view of head. Much enlarged. (Original.)

material. Efforts to rear it from the tuber moth were failures at first, so numerous tuber-moth larvæ were taken from leaf mines and placed on tubers so that there might be no danger of getting mixed material. No specimens of this parasite emerged in these cages, and it was supposed that it was issuing from some other host.

[1] Chittenden No. 2230[01].

Finally a parasite pupa was noted in a leaf mine with the remains of a tuber-moth larva. When the adult issued it proved to be *Zagrammosoma flavolineatum*. More experiments were carried on, using only material where the tuber-moth larvæ occurred as leaf-miners and were less than half grown. The parasite was seen to oviposit in these larvæ, and it was successfully reared through to the adult.

This parasite thus far has not proved to be of much importance, and seems unpromising, as the adult is so slow and deliberate in its movements that a tuber-moth larva in a large mine can move about and often escape the ovipositor of the parasite.

The following record gives the length of its life cycle:

1915.
August 17.—*Zagrammosoma flavolineatum* ovipositing in tuber-moth larva.
August 29.—1 *Zagrammosoma flavolineatum* adult issued. (Male.)
August 30.—2 *Zagrammosoma flavolineatum* adults issued. (Males.)
August 31.—1 *Zagrammosoma flavolineatum* adult issued. (Male.)
September 1.—1 *Zagrammosoma flavolineatum* adult issued. (Female.)
September 2.—2 *Zagrammosoma flavolineatum* adults issued. (Male and female.)
Life cycle 13 days at average mean temperature of 75°F.

SYMPIESIS STIGMATIPENNIS GIRAULT.[1]

During 1914 and 1915 tuber-moth material collected at Pasadena during late fall gave great numbers of a small parasite, the male of which (fig. 20) had branched antennæ. At about the same time an examination of mines on potato leaves often showed a parasitic larva (fig. 21) feeding externally on a partially grown larva of the tuber moth. When these were reared they proved identical with those issuing in the parasite cages.

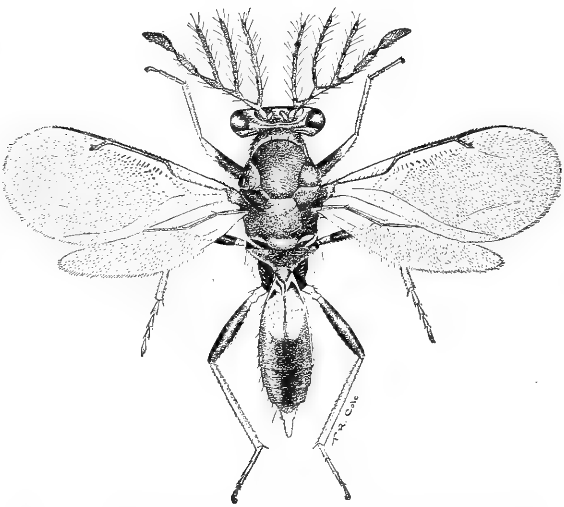


FIG. 20.—*Sympiesis stigmatipennis:* Male. Much enlarged. (Original.)

The parasite was reared with ease in the laboratory, and it oviposited readily in leaf-mining tuber-moth larvæ when half grown or slightly smaller. The host is soon killed and within a short time becomes semiliquid, and the development of the larva is very rapid. When mature (fig. 22) it crawls into a corner of the mine and, without spinning a cocoon, pupates.

[1] Chittenden No. 2230[02].

The pupa (fig. 23) is very flat and black. Several individuals may issue from one host. Under field conditions about equal numbers of males and females issued, but in the laboratory males greatly predominated. Mating takes place as soon as the adults issue, and oviposition shortly after. The females (see fig. 24) probably obtain moisture from the wounds made in the epidermis of the leaf by their ovipositors, as they were often noted after oviposition to back up and apply their mouth parts for some time to the hole made in the leaf. As the tuber-moth larva had generally moved away by this time, it could not have been possible for it to have obtained food from the wound in the larva.

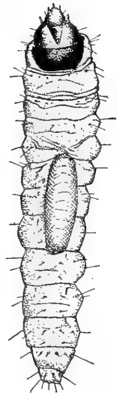


FIG. 21.—*Sympiesis stigmatipennis:* Immature larva feeding on larva of tuber moth. Much enlarged. (Original.)

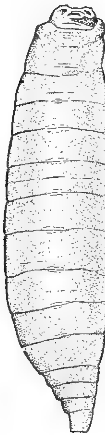


FIG. 22.—*Sympiesis stigmatipennis;* Mature larva. Much enlarged. (Original.)

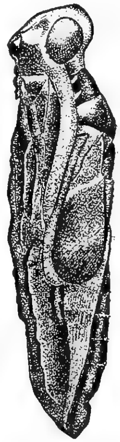


FIG. 23.—*Sympiesis stigmatipennis:* Pupa. Much enlarged. (Original.)

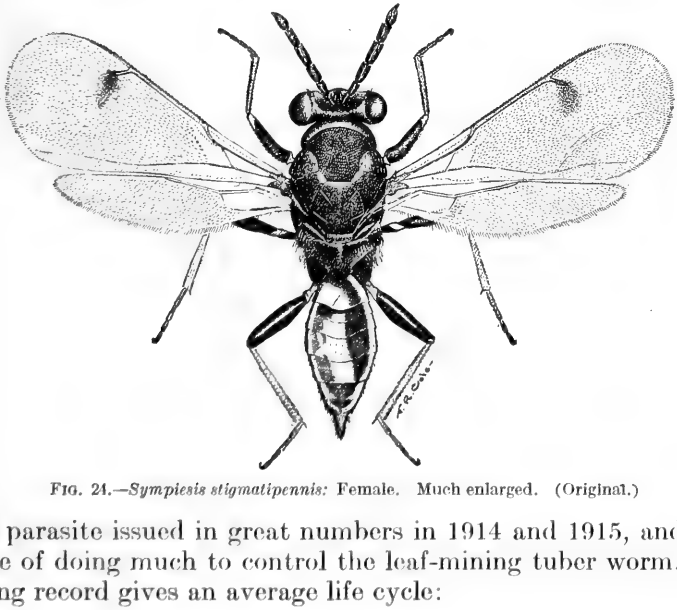


FIG. 24.—*Sympiesis stigmatipennis:* Female. Much enlarged. (Original.)

This parasite issued in great numbers in 1914 and 1915, and gives promise of doing much to control the leaf-mining tuber worm. The following record gives an average life cycle:

1915.

January 26.—Tuber-moth larva parasitized by *Sympiesis stigmatipennis.*

February 21.—3 *Sympiesis stigmatipennis* adults issued. (Males.)

1915.

February 23.—1 *Sympiesis stigmatipennis* adult issued. (Female.)

February 25.—3 *Sympiesis stigmatipennis* adults issued. (Males.)

Life cycle 26 days at average mean temperature of about 52° F.

Longest life cycle noted, 45 days.

CAMPOPLEX PHTHORIMAEAE CUSHM.[1]

During 1913 a very few adults of this species (fig. 25) were reared from tuber-moth material collected near Puente, Cal. These specimens could not be reared in the laboratory. In 1914 and 1915 the parasite became very abundant, and was reared from tuber-moth larvæ, proving it to be a parasite of this species.

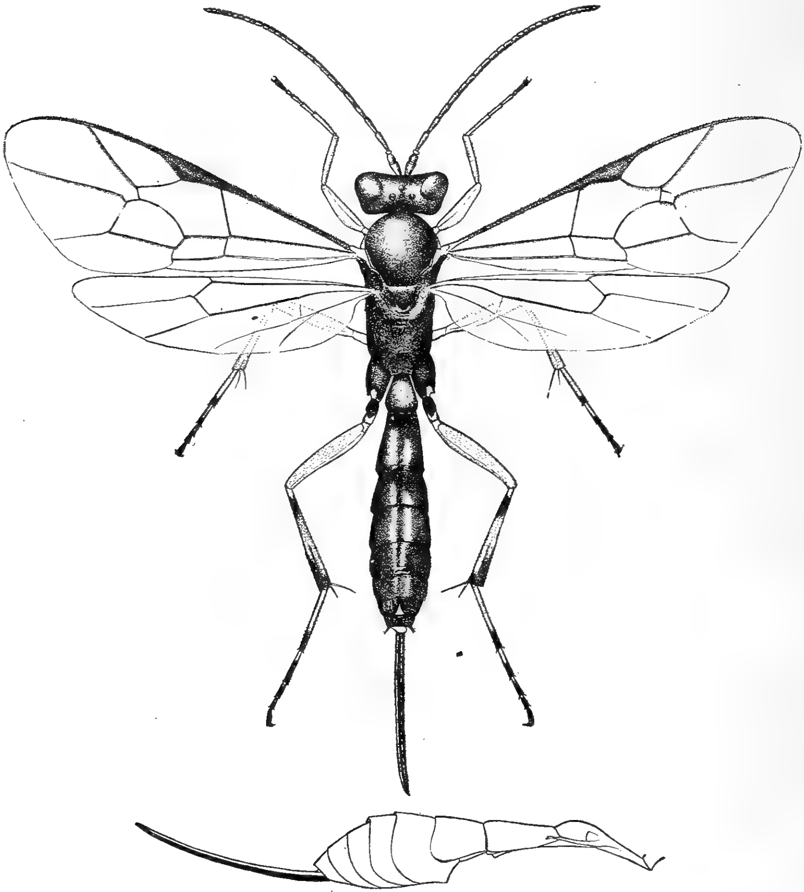


FIG. 25.—*Campoplex phthorimaeae;* Adult female, with lateral view of abdomen. Much enlarged. (Original.)

Tests under laboratory conditions showed that it oviposits in the tuber-moth larvæ only where they act as leaf-miners, and prefers those about half grown. The adult has been noted ovipositing both in the field and in the laboratory. It is so active that the tuber-moth

[1] Chittenden Nos. 2230[03] and 2230[013].

larva seldom escapes. The parasitized tuber-moth larva is readily detected when it becomes mature and seeks a place to pupate. A large dark or reddish spindle is apparent, filling most of its abdomen, and the larva is very restless and seldom stays in one place long enough to spin a cocoon. Finally the host loses all power of locomotion and dies, and within a few hours the mature parasite larva (fig. 26) forces its way through the skin of its host and begins spinning its cocoon (fig. 27). As the parasite larva is almost the size of its host, only one develops on each tuber worm.

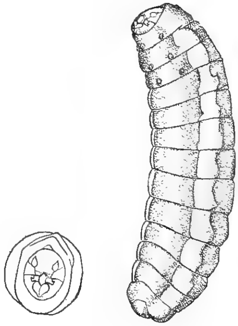


Fig. 26.—*Campoplex phthorimaeae;* Lateral view of mature larva with view of face. Much enlarged. (Original.)

The cocoon is completed within a day or two. It is very heavy, ellipto-cylindrical in shape, light gray, and with a lighter band around the middle. The pupa, removed from its cocoon, is shown in figure 28.

Fig. 27.—Cocoon of *Campoplex phthorimaeae*, parasite of potato tuber moth. Much enlarged. (Original.)

This parasite assisted greatly in reducing the numbers of the tuber moth in the potato tops during 1914 and 1915.

An average life cycle is given below:

December 15, 1914.—Tuber-moth larva parasitized by *Campoplex phthorimaeae.*

February 5, 1915.—1 *Campoplex phthorimaeae* adult issued. (Male.)

February 6, 1915.—1 *Campoplex phthorimaeae* adult issued. (Female.)

Life cycle 52 days at an average mean temperature of about 54° F.

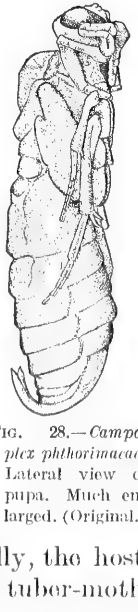


Fig. 28.—*Campoplex phthorimaeae:* Lateral view of pupa. Much enlarged. (Original.)

HABROBRACON JOHANNSENI VIER.[1]

This is probably the best known parasite of the tuber moth, both where it occurs as a leaf-miner and as a pest of stored potatoes. It is well distributed, having been reared from tuber-moth material collected over most of southern California.

It oviposits in the mature larva of the tuber moth after it has spun its cocoon. As many as 13 parasite larvæ have been observed to develop on a single host. The adult female is very active, but seems to prefer to work only in the light, for the parasite has never been reared from material kept in darkened bins.

The larvæ may develop either externally or internally, the host seeming to depend on the position of the egg. After the tuber-moth

[1] Chittenden No. 2230[o1].

larva has been parasitized it does not pupate, but soon breaks down and becomes semiliquid.

The mature larva spins a light but tough white cocoon within the cocoon of its host, thus being well protected. This apparently

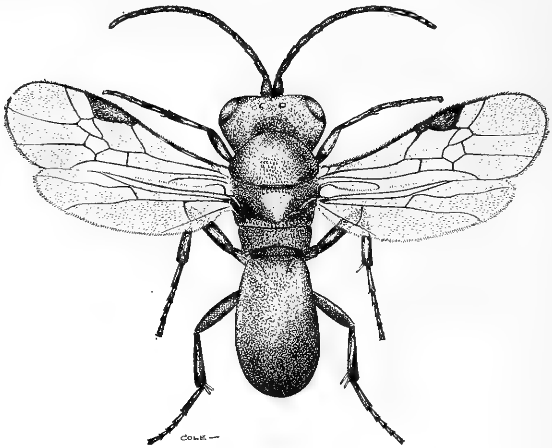


FIG. 29.—*Chelonus shoshoneanorum:* Adult female. Much enlarged. (Original.)

explains its comparative immunity from the secondary parasite *Dibrachys boucheanus.*

The adult feeds quite often at the oviposition wounds of its host. The adults are very hardy and the female is long lived. One female lived from July 19 to September 21, 1914, a period of 64 days, and in this time 291 adults were reared from this one specimen. When the

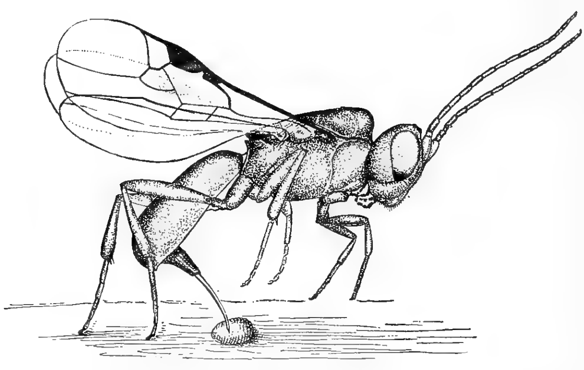


FIG. 30.—*Chelonous shoshoneanorum:* Female ovipositing in egg of tuber moth. Much enlarged. (Original.)

mortality of the stages under laboratory conditions is considered, it will be seen that this species is quite prolific. This female was fed sweetened water four times during this period. The life cycle varies from 10 to 38 days in length.

The record of a shorter life cycle follows:

1913.

September 15.—Tuber-moth larva parasitized by *Habrobracon johanniseni.*
September 18.—Parasite larvæ nearly mature.
September 19.—Parasite larvæ spinning cocoons.
September 20.—Parasite larvæ pupating.
September 25.—4 parasite adults issued.
September 26.—17 parasite adults issued.
Life cycle 10 days at an average mean temperature of 78° F.

CHELONUS SHOSHONEANORUM VIER.[1]

This parasite (fig. 29) has been consistently abundant every year from 1912 to the present time. Efforts to rear it from the larvæ and pupæ of the tuber moth failed, and, at the suggestion of Dr. Howard, the insect was placed with eggs of the tuber moth. Oviposition (fig. 30) took place at once, the parasites usually feeding on the moisture which collected at the wound caused by the ovipositor.

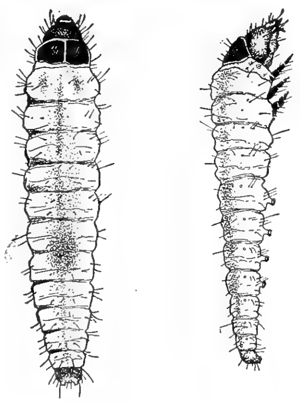


FIG. 31.—Larvæ of tuber moth parasitized by *Chelonus shoshoneanorum.* Much enlarged. (Original.)

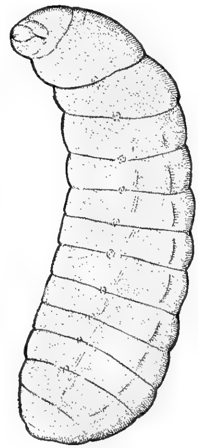


FIG. 32.—*Chelonus shoshoneanorum:* Mature larva. Much enlarged. (Original.)

The eggs of the tuber moth hatched normally, and the young larvæ at once burrowed into the tuber. Later the mature tuber-moth larvæ began to leave the tuber and start their cocoons. Some of the larvæ appeared restless and darkened spindles were noticeable in their bodies (fig. 31), quite similar to those in the case of *Campoplex phthorimaeae.* None of the larvæ pupated, and soon the mature parasite larva (fig. 32) emerged and spun its white cocoon within the cocoon of its host.

This parasite promises to be of value in controlling the tuber moth in the field. It apparently does not work in darkened bins.

The life cycle is divided as follows:

1914.

July 26.—Tuber-moth eggs parasitized by *Chelonus shoshoneanorum.*
July 31.—Tuber-moth eggs hatched.
August 16.—Chelonus larvæ mature.
August 18.—Chelonus larvæ pupating.
August 26.—1 Chelonus adult issued.
August 27.—3 Chelonus adults issued.
August 28.—2 Chelonus adults issued.
Life cycle 31 days at an average mean temperature of about 72° F.

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[1] Chittenden No. 2230°5.

BASSUS GIBBOSUS SAY.[1]

Bassus gibbosus (figs. 33–35) attacks the half-grown tuber worm in leaf mines. Like *Zagrammosoma flavolineatum*, it is apparently of minor importance, and probably for the same reason.

Adults placed on potato leaves containing larvæ of the tuber moth attempted oviposition, but frequently without success. The parasite is rather slow in oviposition, and the larva within the mine is given opportunity to escape the ovipositor.

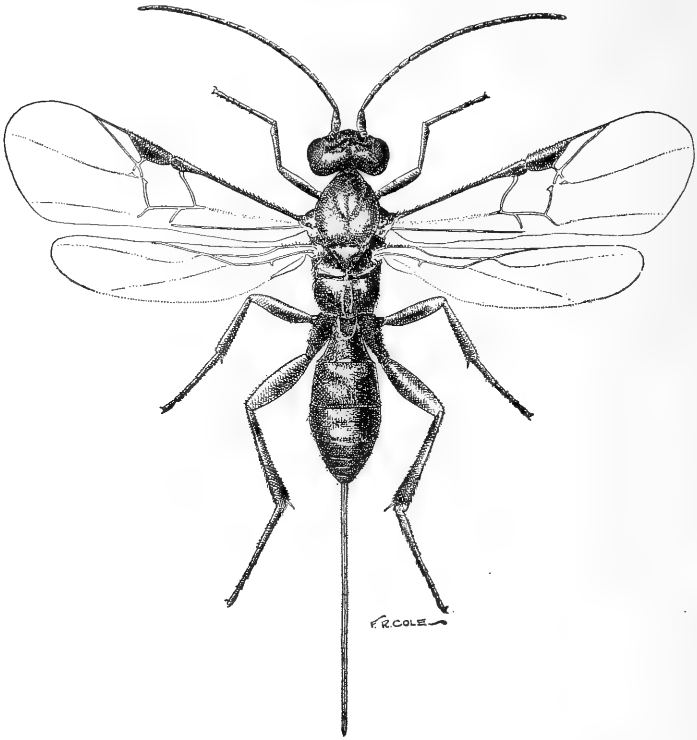

FIG. 33.—*Bassus gibbosus:* Adult female. Much enlarged. (Original.)

This parasite appears in the greatest numbers during the late fall and winter. For this reason its life cycle is of rather long duration, as the following record shows:

1915.
February 8.—Tuber-moth larvæ parasitized by *Bassus gibbosus.*
April 2.—1 parasite issued. (Male.)
April 3.—1 parasite issued. (Female.)
April 7.—1 parasite issued. (Male.)
Life cycle 53 days at an average mean temperature of about 53° F.

The parasite seems to be well distributed throughout southern California.

[1] Chittenden No. 2230[06].

APANTELES SP.[1]

This small active parasite (figs. 36–38) was not observed until 1914, and seems quite scarce except in the vicinity of Pasadena. The half-grown leaf-mining tuber-moth larvæ are attacked. When the parasite has discovered a leaf mine, it cautiously examines it until it has located the position of the tuber-moth larva. The parasite then quickly inserts its ovipositor in the mine. In case it strikes the larva, it oviposits; otherwise it quickly withdraws its ovipositor, inserting it again in a new place. This is repeated until the larva is parasitized, although the difficulty in locating the larva may require a second examination of the mine. Should the parasite discover a larva, however, it seldom leaves until it has been successful in oviposition.

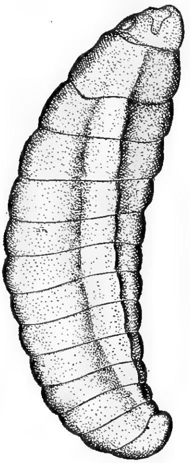

FIG. 34.—*Bassus gibbosus*: Mature larva. Much enlarged. (Original.)

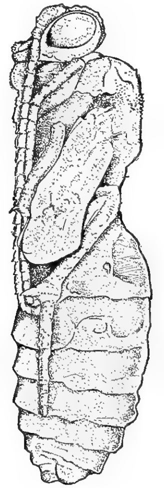

FIG. 35.—*Bassus gibbosus*: Pupa. Much enlarged. (Original.)

This Apanteles is a most promising parasite. The record of an average winter life cycle follows:

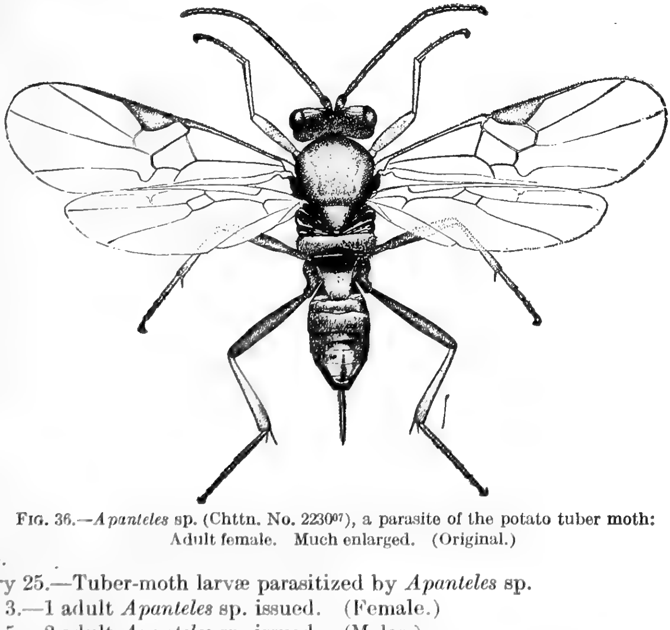

FIG. 36.—*Apanteles* sp. (Chttn. No. 2230⁰⁷), a parasite of the potato tuber moth: Adult female. Much enlarged. (Original.)

1915.

January 25.—Tuber-moth larvæ parasitized by *Apanteles* sp.
March 3.—1 adult *Apanteles* sp. issued. (Female.)
March 5.—2 adult *Apanteles* sp. issued. (Males.)
March 6.—1 adult *Apanteles* sp. issued. (Male.)
Length of life cycle 37 days at average mean temperature of 53° F.

[1] Chittenden No. 2230⁰⁷.

MICROGASTER SP.[1]

This, the most active parasite attacking the tuber moth, prefers half-grown leaf-mining larvæ. This parasite seems the best fitted naturally to be a dangerous enemy of the tuber moth, but during three years' observation has not reached expectations.

The adults (fig. 39) are readily reared at any time from late summer to spring, but never in large numbers. The adult has the shortest length of life of any observed. Even when fed, only one individual lived as long as 11 days. It seems to be fairly well distributed through the San Gabriel Valley.

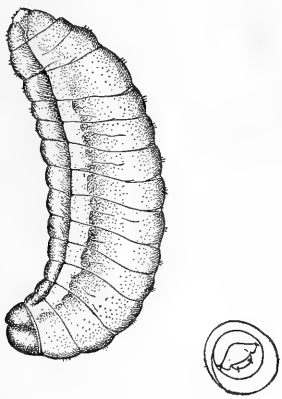

FIG. 37.—Lateral view of mature larva of *Apanteles* sp. (Chttn. No. 2230[07]), with view of fan at left below. Much enlarged. (Original.)

The record of a typical life cycle follows:

1915.

August 18.—Tuber-moth larvae parasitized by *Microgaster* sp.

September 3.—1 adult issued. (Male.)

September 4.—2 adults issued. (Male and female.)

September 6.—1 adult issued. (Male.)

Life cycle 16 days at an average temperature of 73° F.

DIBRACHYS CLISIOCAMPAE FITCH.[2]

The last well-ascertained parasite of the tuber moth was *Dibrachys clisiocampae* Fitch. During 1913 one female was reared from tuber-moth material, but could not be bred through, and as no more issued, it was given up.

FIG. 38.—*Apanteles* sp. (Chttn. No. 2230[07]): Lateral view of pupa. Much enlarged. (Original.)

In the winter of 1914 specimens were captured on potato foliage, and it was later noticed breeding on stored potatoes in the insectary. The parasite oviposits in the mature larvæ in cocoons, and in pupæ and issues from both stages, but usually from the mature larvæ. This parasite works both in the field and in storage. It seems to prefer piles of potatoes, working all through them, and also has been noted to oviposit in dark bins. The egg is shown in figure 40.

The adult (fig. 41) is persistent, and if driven away from a cocoon will return again and again until it oviposits. Fourteen mature larvæ (fig. 42) have been reared from one host. These pupate (see fig. 43) without spinning cocoons, and within the cocoon of their host. The parasite does not seem to be very well distributed, having been found only in Whittier and Pasadena, Cal. It seems at first glance to be the most effective parasite of the tuber moth, but probably this is not the case. It is not as effective as others under field conditions,

[1] Chittenden No. 2230[08].

[2] Chittenden No. 2230[09].

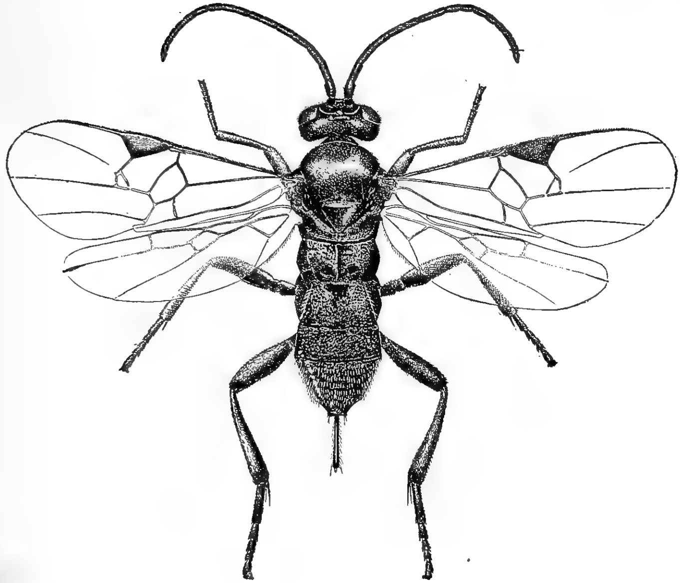

FIG. 39.—*Microgaster* sp., a parasite of the potato tuber moth: Adult female. Much enlarged. (Original.)

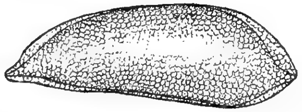

FIG. 40.—*Dibrachys clisiocampae:* Egg, lateral view. Greatly enlarged. (Or ginal.)

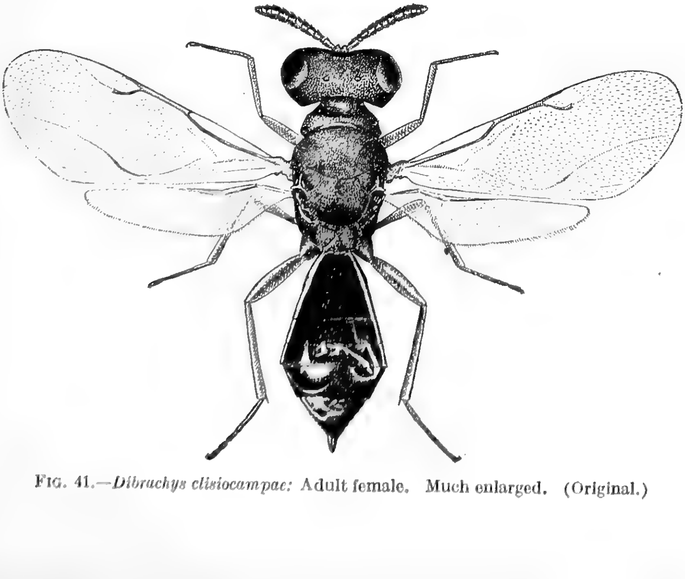

FIG. 41.—*Dibrachys clisiocampae:* Adult female. Much enlarged. (Original.)

and on stored potatoes conditions are such that any parasite is of doubtful value. In addition, it seems to have one unfortunate habit, that of becoming at times a hyperparasite on *Campoplex phthorimaeae*. This habit is so unusual, however, as to be unimportant.

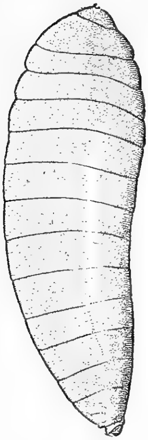

FIG. 42.—*Dibrachys clisiocampae:* Mature larva. Much enlarged. (Original.)

The record below gives the length of a life cycle:

1915.

August 8.—Tuber-moth larvæ parasitized by *Dibrachys clisiocampae*.
August 16.—Parasite larvæ mature.
August 18.—Parasite larvæ pupating.
August 25.—4 parasite adults issued. (Male and female.)
August 26.—7 parasite adults issued. (Male and female.)
August 27.—1 parasite adult issued. (Female.)
Length of life cycle 13 days at an average mean temperature of 75° F.

OTHER PARASITES.

Other parasites [1] were reared from time to time in small numbers from tuber-moth material collected in the San Gabriel Valley. They never became at all common. Efforts to rear them in the laboratory have been unsuccessful thus far. Both have been seen on occasion to oviposit in small leaf-mining tuber-moth larvæ, but no parasites have issued, and so they have not as yet been proven to be parasites of the tuber moth.

NEPEIRA BENEVOLA VAR. FUSCIFEMORA CUSHM.[2]

For some time this parasite (fig. 44) was considered identical with *Campoplex phthorimaeae* Cushm. The differences noted seemed to be variations within the species. While Mr. Cole was making drawings of the parasites, he noted that there were three separate types.

Nepeira benevola var. *fuscifemora* Cushm. closely resembles *Campoplex phthorimaeae*, both in appearance and life history, but has never become as abundant as the latter. It oviposits in half-grown leaf-mining tuber-moth larvæ.

Larvæ parasitized November 12 have given adult parasites December 12, a length of life cycle of 30 days, at an average mean temperature of about 63° F.

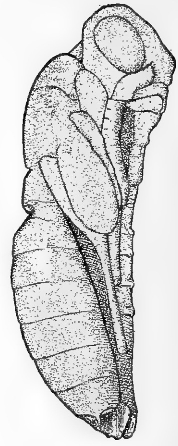

FIG. 43.—*Dibrachys clisiocampae:* Pupa, lateral view. Much enlarged. (Original.)

PERCENTAGE OF PARASITISM.

The percentage of parasitism has fluctuated so greatly in the time it has been under observation that it is difficult to give even approximate figures. The lowest parasitism noted was 40 per cent and the highest was 95 to 100 per cent. The

[1] Chittenden Nos. 2230⁰¹⁰ and 2230⁰¹¹.

[2] Chittenden No. 2230⁰¹².

parasites are undoubtedly of value in limiting the increase of the tuber moth while it works in the tops, thus decreasing infestation of the tubers.

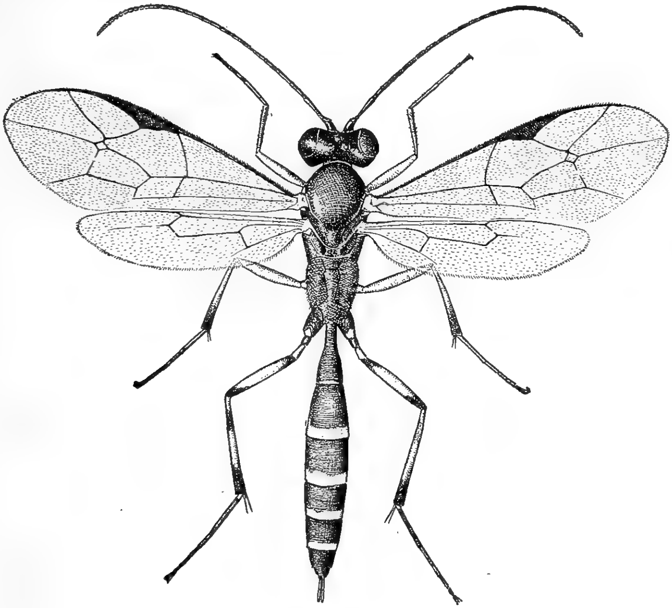

FIG. 44.—*Nepeira benevola:* Adult female. Much enlarged. (Original.)

A review of the parasites shows that they attack the tuber moth under the following conditions:

On leaf-mining tuber moth.	On storage tubers.
[1] 2230[01]. *Zagrammosoma flavolineatum.*	
2230[02]. *Sympiesis stigmatipennis.*	
2230[03] and 2230[013]. *Campoplex phthorimaeae.*	
2230[04]. *Habrobracon johannseni.*	[1] 2230[04]. *Habrobracon johannseni.*
2230[05]. *Chelonus shoshoneanorum.*	[1] 2230[05]. *Chelonus shoshoneanorum.*
[1] 2230[06]. *Bassus gibbosus.*	
2230[07]. *Apanteles* sp.	
[1] 2230[08]. *Microgaster* sp.	
2230[09]. *Dibrachys clisiocampae.*	[1] 2230[09]. *Dibrachys clisiocampae.*
[1] 2230[012]. *Nepeira benevola* var. *fuscifemora.*	

[1] Of doubtful importance.

PREDATORS.

Predacious enemies of the tuber moth appear economically unimportant and will be considered very briefly.

Triphleps insidiosus Say and the larva of *Chrysopa californica* Coq. have on a few occasions been noted to destroy the eggs and newly hatched larvæ. As both these insects prefer aphids to the tuber moth, and as aphids are generally present on the potato tops, it seems that the destruction of the tuber-moth eggs and larvæ is more accidental than natural.

Several species of spiders which are found in the fields spin webs in which dead tuber moths have been noticed, and in a few cases the spiders have been observed killing moths caught in the webs.

ARTIFICIAL CONTROL.

INDIRECT METHODS, GOOD FARMING.

A study of the literature of the tuber moth shows that many writers, beginning with Capt. Berthon (1), have recommended good farming and careful harvesting and storing of tubers as the best remedies against the tuber moth. The powers of reproduction of this insect have given weight to these arguments, and a study of cultural methods in relation to tuber-moth infestation has proved the correctness of their recommendations.

Through the kindness of Mr. S. S. Rogers, of the University of California, the writer was enabled to compare the results of different cultural methods. The test field, situated near Van Nuys, Cal., had every conceivable variation in culture. Planting depth varied from 2 to 16 inches. Each plat contained both flat and ridged culture and was harvested in three parts, so that each variation in culture had early, medium, and late harvesting.

The results may be briefly summarized as follows:

Taking the entire field as an average, the percentage of infestation in the plats having ridged culture was 8 per cent less than in those having flat culture.

In the same way the plats harvested early had 4 per cent less infestation than those harvested at the medium period and 9 per cent less than those harvested late.

In the experiments with depth of planting results were even more striking. In the plats planted 2 inches deep (many tubers were exposed) the vines were dead, and the percentage of infestation of the tubers varied from 98 to 100. From this the percentage of infestation became steadily less, as the depth of planting was increased, until at a depth of 6 inches a minimum was reached, several plats giving entirely clean potatoes and the average of infestation being low. In the plats where deeper planting was used, the potatoes seemed to grow as near the surface as where 5 to 6 inches planting depth was used, and consequently there was no difference in freedom from the moth.

Results from the experiments as to time of planting varied so greatly that it was evident several other factors have more to do with determining infestation than the time of planting. The same might be said of the variety test, except that the tubers of varieties where the vine stayed green the longest suffered least from the moth.

On an average the results show the value of the recommendations given for fighting the tuber moth by culture.

These may be stated as follows:

(1) Plant as deep as practicable (5 to 6 inches).

(2) Use ridge culture, *i. e.*, ridge the rows (fig. 45).

(3) Harvest as early as possible.

(4) Harvest before the potato tops become so dry as to drive the partially grown larvæ to descend and work on the tuber.

In harvesting the tubers, several rules must be followed to keep the tubers from infestation:

(1) The sacks should *never* be covered with potato tops, as the larvæ leave these when they wilt, and enter the potatoes.

FIG. 45.—Potato field showing careful hilling. Walker, Cal. (Original.)

(2) The sacks should be sewed as soon as possible and hauled from the field.

(3) Potatoes should never be left in the field or exposed to the moth over night.

(4) All cull potatoes should be gathered up within two weeks and either fed to stock at once or destroyed. If left in the field they are a menace to the neighbors, and to the grower himself, for the following crop.

After the potatoes are harvested they should be marketed at once, unless the grower has storage facilities and is willing to take the trouble to treat the potatoes.

While there are good reasons for destroying the potato vines yet there appear to be even better reasons for not doing so. Destroying the potato vines kills all stages of the tuber moth within, but it also kills the parasites. The tuber moth is more apt to pupate under clods and rubbish in the field than are any of the parasites, hence the destruction of potato tops would be a more serious check to the parasites than to the tuber moth. It seems that if growers destroy waste tubers and keep the rest protected so that the tuber moth must breed on potato tops, the parasites will keep the tuber moth from becoming dangerously abundant.

DIRECT CONTROL METHODS.

Experiments were made to determine a cheap practical method of treating tubers infested with the tuber moth. As the tuber takes up odors and flavors readily, and retains them for indefinite periods, only a few methods were tried.

The only promising unobjectionable applications tested were formalin dilutions and water used as dips, and carbon disulphid and hydrocyanic-acid gas as fumigants. Of these four, the only one which was at all successful was carbon disulphid.

Carbon disulphid naturally has many advantages as a fumigant for potatoes. It does not injure the tubers, it can be applied for long periods and thus penetrate thoroughly, and finally, it is heavier than air and if liberated at the top will go entirely through a pile to the floor. Various dosages and periods were used for fumigation, but it was early apparent that for all-around results the material should be used at the rate of 2 pounds to 1,000 cubic feet, and fumigation should last 48 hours. At this strength the larvæ and adults, and practically all the pupæ and eggs, will be killed, and the long exposure to the vapor insures thorough penetration.

If potatoes are to be stored they should be fumigated promptly. Cheap gas-tight bins may be made by lining temporary structures with tarred paper and painting the seams. If the tubers are noticeably infested the fumigation should be repeated in a week in summer, or in two weeks in winter. Careful watch should be kept, and if the tuber moth is still working, another fumigation should be given.

In fumigating with carbon disulphid the liquid should be placed on top of the sacks in shallow tin pans, and care should be taken not to expose the gas to fire, as it is explosive when mixed with air and ignited.

OTHER REMEDIES.

TRAPPING THE ADULTS.

As the adult is attracted to light, some authors recommend trapping with lanterns. This remedy is of questionable value, as not all the adults could be trapped, and there is much doubt as to whether the numbers could be sufficiently reduced to make a difference at harvest time. In this connection it must be remembered that it is the multiplication of the insect in storage that causes practically all the loss.

QUARANTINE.

Quarantine as a method of keeping out the tuber moth has attracted considerable attention in the Western States in recent years. A quarantine of one district against another when the tuber moth is established in both places is of little value, as the numbers of this insect in any one year are not influenced as greatly by its numbers the preceding year, or by any that might be introduced, as by food and climatic conditions. The great interstate shipment of potatoes throughout the West proves that the potato question is a factor which affects many of the people living in those States, and a hasty or ill-advised quarantine might cause losses which would more than offset any advantages to be gained from it.

In conclusion it should be said that while the tuber moth is always a menace in warmer climates, it is by no means a fatal potato pest, and its damage, if not totally eliminated, can at least be minimized by rational farming methods and a knowledge of the habits of the insect. For this reason whenever there has been an outbreak of the moth in a new district the conditions[1] in this district should be studied and means devised to prevent a recurrence of injury.

SUMMARY.

(1) The tuber moth injures the potato by destroying the leaf surface and tunneling in the substance of the tuber.

(2) Its life history is variable, but in southern California all the stages exist at all times of the year.

(3) The numbers of the insect should be reduced by practicing good farming and leaving no tubers exposed for the insect to work on.

(4) Potatoes should be harvested and marketed as rapidly as possible, unless the grower has facilities for storage and is prepared to treat the potatoes if necessary.

(5) Once the tubers become infested the best way of ending the damage is to fumigate with carbon bisulphid, using 2 pounds to 1,000 cubic feet of air space (measured before storing the tubers) and allowing 48 hours for fumigation.

(6) Clean or uninfested potatoes should be kept away from the moth.

(7) Potatoes should never be left in the ground after they are ripe and where the soil is dry.

(8) When tubers are infested and facilities are lacking for storing in bins, the progress of infestation can be checked by holding the potatoes in cold storage. The temperature should be about 37° to 40° F. This should be adopted only as a temporary method in keeping potatoes from deteriorating in value while they are being held for a rise in price.

[1] This refers especially to various methods of storing potatoes.

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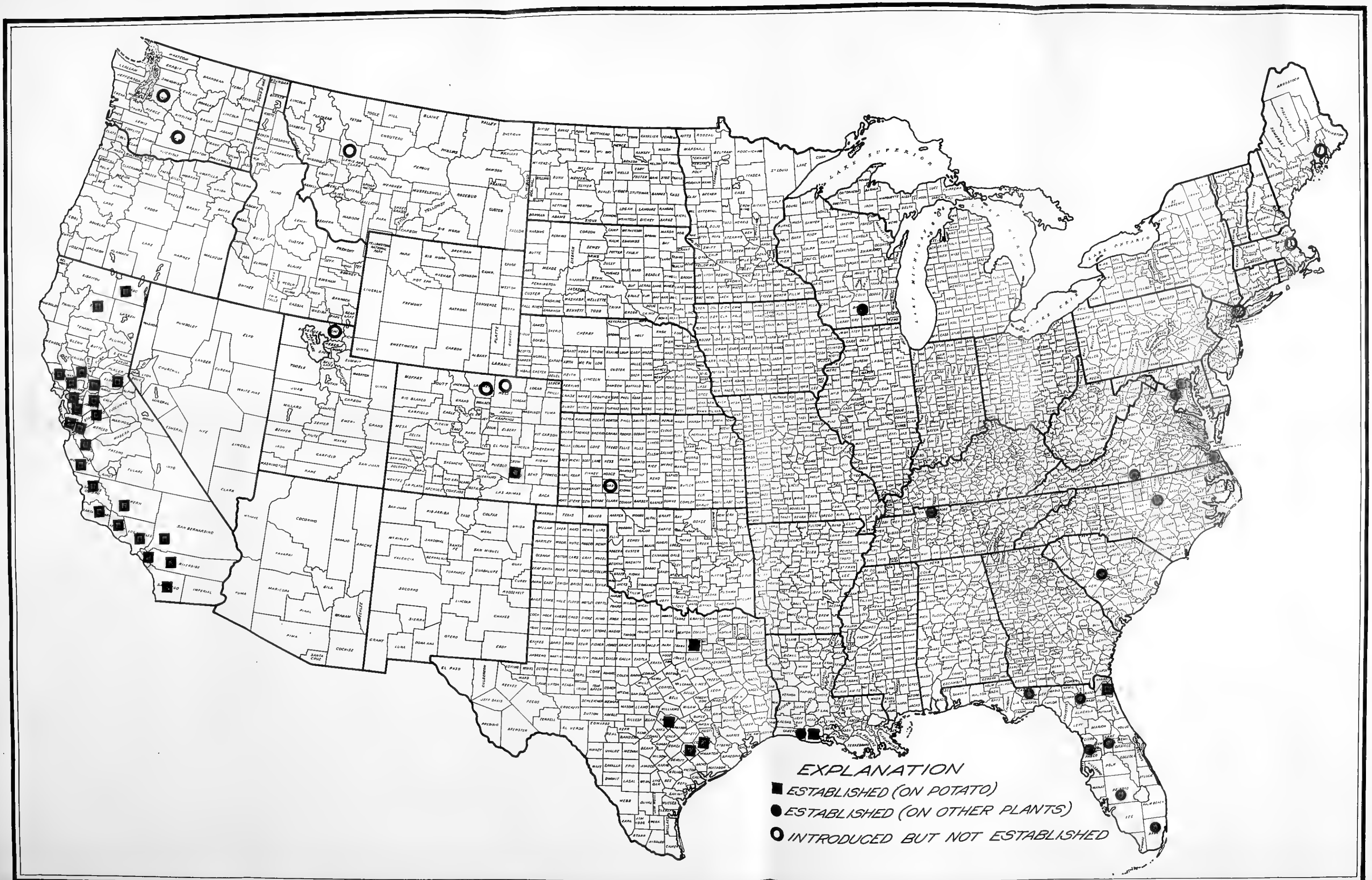
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
EXPLANATION
ESTABLISHED (ON POTATO)
ESTABLISHED (ON OTHER PLANTS)
INTRODUCED BUT NOT ESTABLISHED

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 428

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MEDICAGO FALCATA, A YELLOW-FLOWERED ALFALFA.

By R. A. OAKLEY, *Agronomist*, and SAMUEL GARVER, *Scientific Assistant, Office of Forage-Crop Investigations.*

CONTENTS.

	Page.
Introduction	1
Introduction of Medicago falcata into the United States	2
Natural distribution	5
Climatic and soil requirements	7
Botanical history	8
Botanical description and relationship	13
Botanical description	13
Botanical relationship	24
Agricultural history	33
Common names	34
Agronomic characteristics	35
General habits of growth	36
Characteristics of the vegetative growth	36
Stem characteristics	37
Periods of growth	38
Hardiness	41
Drought resistance	45
Agronomic characteristics—Continued.	
Seed production	47
Yields of hay	49
Feeding value	50
Cultural investigations	51
Broadcast seedings	52
Cultivated rows	53
Hills	53
Transplanting	54
Seeding on the range	55
Possibilities in selection and hybridization	56
Selection	56
Hybridization	57
Difficulties in establishing new strains	59
Present agronomic status	61
Summary	63
Literature cited	67

INTRODUCTION.

Eight years have elapsed since *Medicago falcata* L. was brought to this country with the serious view of utilizing it as a cultivated forage crop.[1] During this period much attention has been directed to-

[1] From 1910 to 1913, inclusive, investigations were conducted with *Medicago falcata* at Brookings, Highmore, and other points in South Dakota in cooperation with the South Dakota Agricultural Experiment Station.

The writers wish to acknowledge their indebtedness to Mr. H. L. Westover for valuable assistance rendered in translating botanical descriptions and in reviewing literature and to Mrs. Katherine S. Bort for assistance in connection with the literature consulted in the preparation of the subject matter.

NOTE.—This bulletin is intended primarily for those who are interested in alfalfa breeding.

ward the species in various ways and an interest manifested in it that is quite as widespread as that in any other plant immigrant of recent times. The fact that it is classed as a variety of alfalfa would alone have been sufficient advertisement, but to be described as a hardy and drought-resistant strain obtained for it at once almost universal recognition. Eight years would appear to be a sufficient period of time in which to determine to a reasonable degree the agricultural merits of any new crop, but in the case of *Medicago falcata* more time will be required before the true status of this species can be ascertained and its value accurately estimated.

It is true that many of the investigators who have worked with it, or rather with a few forms of it, have long since condemned it as being of little value. On the other hand, a few have seen in it the solution of the whole problem of a hardy and drought-resistant alfalfa. Both of these views are undoubtedly extreme, the first being based on scanty information or a study of insufficient material; the second, somewhat at least on sentiment. Those who have worked carefully and open-mindedly with all the available forms of the species are convinced that certain forms have much potential value if properly utilized.

One of the purposes of this bulletin is to correct many of the extreme and erroneous opinions that have obtained regarding *Medicago falcata* by setting forth in as fair and unbiased a manner as possible what are believed to be reliable data for the aid of plant breeders and others who are interested in the species.

INTRODUCTION OF MEDICAGO FALCATA INTO THE UNITED STATES.

The first importation of *Medicago falcata* to the United States of which there is a record was made by the Department of Agriculture in 1897, through the instrumentality of Prof. N. E. Hansen, who was commissioned by the Secretary of Agriculture to visit Europe and Asia for the purpose of procuring promising plants new to the agriculture of this country. Accidental importations of seed were made at an earlier date, as indicated by specimens of fully developed plants found in the United States National Herbarium, collected in Delaware by A. Commons in 1896. The collector's notes merely state that the plants were found growing in waste places. Such accidental introductions as may have occurred failed to produce any considerable number of plants in this country, since the species even now is not common in any locality.

Since 1897 the Department of Agriculture has conducted a systematic search for the numerous forms of *Medicago falcata.* This has been inspired partially by the belief that the species of itself possesses promise as a forage crop in the colder and drier portions of the country and partially because of the recognized part which it has played in the development of the most hardy and drought-resistant commercial strains of alfalfa and the promise it presents from a plant-breeding standpoint. In connection with this systematic search, Prof. Hansen made two trips to Europe and Asia for the express purpose of collecting seed of the numerous forms of the species. The first trip was made in 1906 and the second in 1908. Mr. Frank N. Meyer, the department's regular agricultural explorer, has also devoted much attention to procuring seed of the various forms of the species, especially from localities in Asia. The efforts of both explorers were directed by the Office of Foreign Seed and Plant Introduction of the Bureau of Plant Industry. Through its contacts with various collectors and investigators that office has, in addition, succeeded in obtaining a large number of forms from many parts of the Old World where the species is indigenous, so that the collection now in the possession of the department is probably more nearly complete than any that has previously been brought together. Furthermore, it probably represents nearly all of the striking forms at present in existence.

As in the case of many other wild plants, difficulty attended the procuring of seed, so that only small quantities of most of the forms were obtained. In a few cases, however, collectors offered to supply it at a comparatively low price, approximately $1 per pound.

Each lot of seed procured by the Department of Agriculture was assigned a regular accession number, which serves the purpose of identification. Below is a list of these numbers, together with brief notes taken from the published inventories of the Office of Seed and Plant Introduction.

842. 50 miles east of Rovnaya, Russia.
9748. Madrid, Spain. From Botanic Gardens.
19534. Valuiki, Samara Government, Russia.
20717. Kharkof Province, Russia. From wild plants.
20718 and 20719. Omsk, Siberia. From wild plants.
20720. Irkutsk, Siberia. From hay in market.
20721. Samara Province, Russia. From wild plants.
20722. Saratof Province, Russia. From wild plants.
20724. Tomsk, Siberia. From wild plants.
20725. Don Province, Russia. From wild plants.
20726. Samara Province, Russia. From wild plants.
23625. Orenburg, Russia.
24452. Obb, Tomsk Province, Siberia. From wild plants.
24453. Omsk, Akmolinsk Province, Siberia. From wild plants.
24454. North of Irkutsk, Siberia. From wild plants.
24455. Ten miles north of Semipalatinsk, Siberia. From wild plants.
24456. Station Charonte, Siberia. From wild plants.

26927. Kashmir, India. From plants grown under irrigation.
28041. Between Dushet and Passanura, Caucasus, Russia. From wild plants.
28070. Semipalatinsk region, Siberia. From wild plants.
28071. Orenburg region, Russia. From wild plants.
28918. Christiania, Norway. From Botanic Garden.
28940 and 28941. Copenhagen, Denmark. From Botanic Garden.
29139. Lahul, India.
29913. Jerusalem, Palestine.
30027. Svalof, Sweden. From wild plants as found in Sweden.
30200. Lower Austria. From wild plants.
30433. Leh, India.
30436. Kargil, India.
30955. Valley of the Chong Djighilan, Tien Shan Range, Chinese Turkestan. From wild plants.
31005. Petrograd, Russia. Botanic Gardens.
31303. Valley of the Chong Djighilan, Tien Shan Range, Chinese Turkestan. From wild plants.
31649. Iskardo, India.
31956. Nice, France.
32178. Ust-Kamenogorsk, Siberia. From wild plants.
32179. Along River Tom, near Tomsk, Siberia. From wild plants.
32180. Kuznetsk district, east of Barnaul, Siberia. From wild plants.
32389. From western Siberia.
32409. Near Sarepta, Russia. From wild plants.
32411. Near Saratof, Russia. From wild plants.
32412. Krassny Koot, Samara Government, Russia. From wild plants.
33465. Semipalatinsk, Siberia.
34116. Vicinity of Semipalatinsk, Siberia. From wild plants.
35311. Novospassko, Russia. From wild plants.
35312. Omsk district, Siberia. From wild plants.

The above list of introductions would indicate that the efforts of the Department of Agriculture were not confined to obtaining seed from a particular locality or region. Nevertheless, since the project was inaugurated mainly to aid in the solution of the hardy and drought-resistant alfalfa problems, special attention was focused on parts of Russia and Siberia having climatic conditions comparable with the colder and drier portions of the North and Northwest. Although many plants, especially perennials, are found growing under a wide range of climatic conditions, it is nevertheless of interest in the case of the introduction of *Medicago falcata* to compare certain features of the climate of points in Russia and Siberia, where the species is found growing naturally in some abundance, with points in the northern and northwestern parts of the United States. Table I indicates the seasonal and normal annual precipitation and the maximum, minimum, and mean annual temperatures for points in Russia and Siberia and in certain Northwestern States.

TABLE I.—*Seasonal and normal annual precipitation and maximum, minimum, and mean annual temperatures of points in Russia and Siberia and in some of the Northwestern States.*

Locality.	Precipitation (inches).					Temperature (°F.)		
	Winter.	Spring.	Summer.	Autumn.	Annual.	Maximum.	Minimum.	Normal annual.
Russia and Siberia:								
Charonte	1	1 to 2	8 to 12	2 to 3	12 to 18	97.5	−53	32
Irkutsk	1 to 2	2 to 3	6 to 8	4 to 6	13 to 19	103	−51	32
Kharkof	3 to 4	4 to 6	6 to 8	4 to 6	19 to 28	97.5	−40	42
Lake Baikal region	1	1 to 2	8 to 12	1 to 2	11 to 17	103	−58	32
Omsk	1	2 to 3	6 to 8	2 to 3	11 to 15	98.5	−56	32
Orenburg	3 to 4	3 to 4	4 to 6	3 to 4	13 to 18	105.5	−43	39
Semipalatinsk	1	1 to 2	3 to 4	2 to 3	7 to 9	106.5	−51	39
Saratof	3 to 4	3 to 4	4 to 6	4 to 6	14 to 20	108	−40	42
Tomsk	3 to 4	3 to 4	8 to 12	4 to 6	18 to 26	95	−60	32
Yakutsk	1	1 to 2	4 to 6	2 to 3	8 to 12	102	−84	14
Montana:								
Havre	1.79	3.58	6.00	2.30	13.67	108	−57	41.9
Billings	1.64	5.57	4.65	3.10	14.96	112	−49	47.2
Glasgow	1.65	4.82	4.02	2.04	12.53	113	−56	40.2
North Dakota:								
Minot	1.24	4.12	7.44	3.26	16.06	109	−47	38.8
Dickinson	1.39	4.70	7.17	2.32	15.58	110	−47	40.4
Bismarck	1.66	5.42	7.66	2.90	17.64	107	−45	40.0
Jamestown	1.88	5.66	9.29	3.19	20.02	106	−40	39.9
Devils Lake	1.52	5.24	10.07	3.33	20.16	103	−44	36.4
South Dakota:								
Pierre	1.40	5.44	7.44	2.35	16.63	110	−40	45.6
Huron	1.57	6.56	9.36	3.61	21.10	108	−43	42.1
Rapid City	1.36	6.26	8.25	2.82	18.69	106	−40	45.2
Highmore	.90	5.03	8.01	2.81	16.75	108	−45	44.7
Nebraska:								
Valentine	1.74	6.85	10.03	3.84	22.46	106	−38	46.3
North Platte	1.34	6.08	8.39	3.05	18.86	107	−35	48.2

NATURAL DISTRIBUTION.

In both Europe and Asia *Medicago falcata* has a very wide distribution, as the previous list and accompanying map would indicate. (Fig. 1.) The data from which this map was prepared were obtained from various published floras of Europe and Asia and from correspondents and explorers of the Department of Agriculture. The points where the species has been reported in literature as being found growing wild are designated, as well as those localities from which seed has been collected from plants growing without cultivation and sent to this country. To what extent the distribution of *Medicago falcata* is strictly a natural one can be estimated only broadly. However, the chances are very much in favor of the species being truly indigenous over a large portion of its present range, with the possible exception of western Europe, since its dissemination through the agency of man has been very largely incidental.

Outlining the distribution of *Medicago falcata* by means of the data that are available, it is found to occur in moist western England, in Norway to the sixtieth parallel of latitude, and generally throughout Sweden. It is common in central and southern Russia and in Austria, France, Spain, and other Mediterranean countries. In Siberia its range extends north at least to the sixty-third degree of latitude in the mountain regions of Vilyuisk and Yakutsk. Han-

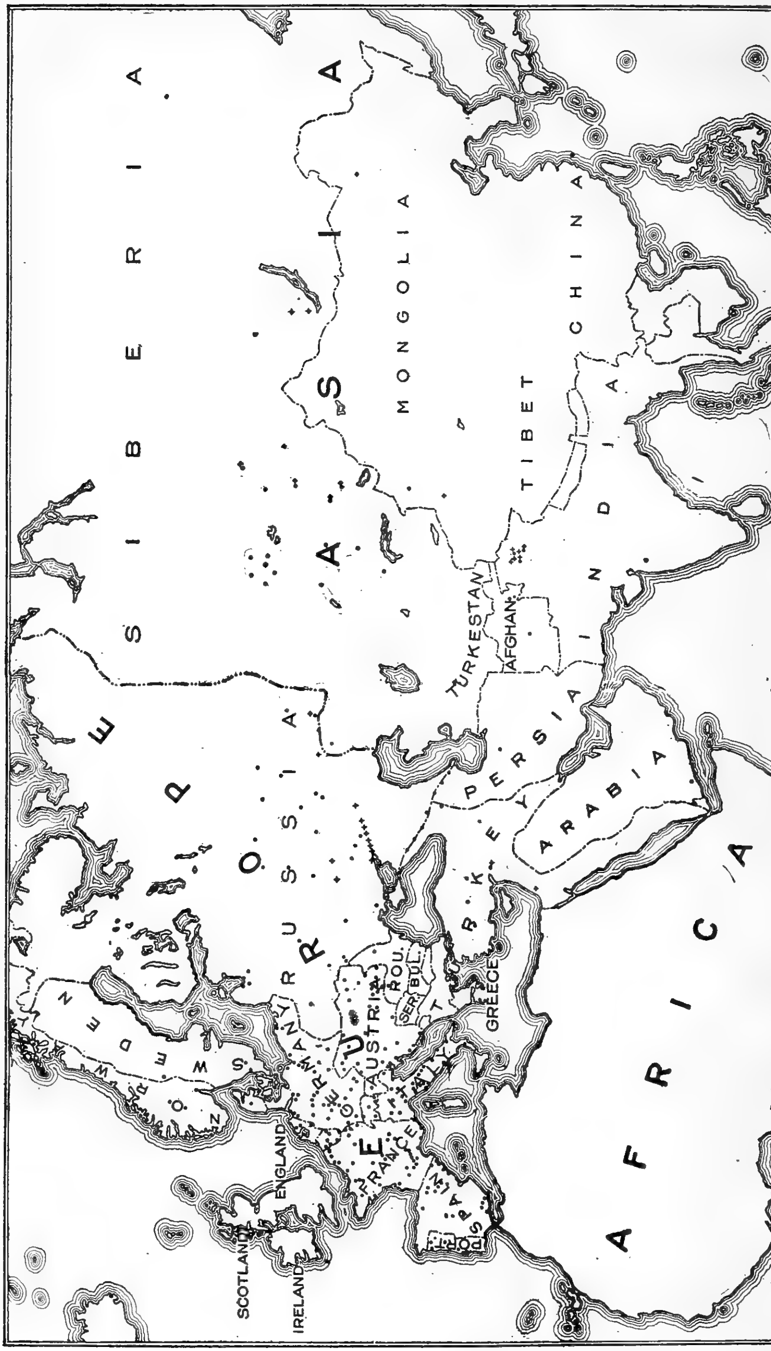

FIG. 1.—Sketch map of Europe and portions of Asia, showing (by round dots) the localities where *Medicago falcata* has been found growing wild and (by small crosses) the localities from which seed of this species has been imported by the United States Department of Agriculture.

sen (*26*, p. 10, 14)[1] is of the opinion that its northeastern limit is be-

[1] The numbers in italic type refer to "Literature cited," pp. 67–70.

tween Verkhoyansk and Yakutsk and that Lake Baikal may be considered its eastern limit with the exception of the locality around Verkhneudinsk, more than 100 miles east of Lake Baikal and Charonte. The range of the species in eastern Asia extends southward to Peking and westward following the northern edge of the great Mongolian Desert, including the region south of the Transbaikal Mountains and across the Himalayas into northern and western India. Continuing westward, it extends through Turkestan, Persia, Syria, Palestine, and European Turkey. So far as has been reported, the species is not indigenous along the Mediterranean region in northern Africa.

There are no localities in which *Medicago falcata* is especially abundant throughout the wide region over which it occurs. According to Meyer and others, the section of Siberia in which it is most abundant is that lying to the north of Semipalatinsk. Hansen reports it to be very common in the Provinces of Tomsk and Akmolinsk in western Siberia; likewise in the country adjacent to the Irtish River and in the district immediately to the east of Lake Baikal. According to Dr. N. H. Nilsson,[1] of the Experiment Station, Svalof, Sweden, it is found in considerable abundance on dry, sandy soils in many parts of Sweden.

CLIMATIC AND SOIL REQUIREMENTS.

Medicago falcata occurs naturally under a great variety of soil and climatic conditions. It is found in moist as well as in dry climates and on soils ranging in character from stiff, heavy clay to almost pure sand. That its requirements with regard to both factors are similar to those of *Medicago sativa* is clearly shown in the nature of its distribution. However, it seems to have a greater range of general adaptability than *Medicago sativa* and is also less exacting in both its soil and climatic requirements.

It is on the dry steppes of Russia and Siberia that the species attains its greatest importance, and over a large portion of that general region it is a fairly common constituent of the native vegetation. The area in which it is most plentiful under humid climatic conditions is in Norway and Sweden on sandy soils, the calcareous nature of which doubtless has much to do with its abundance.

With regard to altitude, the species has an unusual range from below sea level in Palestine to 13,000 feet elevation in Afghanistan, according to J. G. Baker (*4*). Meyer found forms of it growing at an altitude of over 4,000 feet between Dushet and Passanura, Caucasus, Russia, and at 3,700 feet in the Valley of the Chong Djighilan, Tien Shan Range, Chinese Turkestan. Booth Tucker[1] reports it as occurring in India in the Lahul Valley at an elevation of between

[1] In letter on file in the United States Department of Agriculture.

10,000 and 11,000 feet, in a region surrounded by glaciers and covered with snow during the winter months.

With regard to temperature, there are few perennial species that are found growing naturally under the extremes of heat and cold that occur throughout the natural range of *Medicago falcata.* In parts of India and southwest Asia it is subjected to extremely high summer temperatures, but is exposed to only a moderate winter climate. In the vicinity of Yakutsk, Siberia, it meets with hot, dry summers and temperatures as low as −84° F. during the winter. Between these extremes it is found growing naturally under equable climatic conditions in parts of western Europe, notably in Spain and France and in the Scandinavian Peninsula.

Growing as it does under such a great variety of conditions—in many cases remote from the influence of agriculture or commerce—it is not surprising that the species has developed many forms and that it exhibits a tendency toward the production of types peculiar to the various natural geographic regions. That such is the case is strongly indicated by the many introductions made by the Department of Agriculture from numerous localities. However, it will require careful and extensive investigations to determine to what extent in this species plant type is correlated with natural conditions. The material which the department has succeeded in obtaining shows rather clearly that the forms from the high steppe regions of Russia and Siberia are in general quite different from those commonly found in northern India and from at least some of the forms found in southern Russia.

From the vicinity of Irkutsk, Siberia, the department has obtained a distinct form, apparently peculiar to that region, which is characterized by its broad crown and very fine decumbent stems. This region, it will be noted, has a normal annual precipitation of 13 to 19 inches, fairly well distributed throughout the year. The extremely broad-crowned decumbent forms have been procured only from southern Russia in the general region represented by the Provinces of the Don Cossacks and Kharkof. The forms commonly found in India approach sweet clover (*Melilotus alba*) in general appearance, especially in color and texture of foliage, and are quite distinct from those of the high steppes of Russia and Siberia. So far as the material in the possession of the department indicates, the closest resemblance to the forms from India is found in certain forms procured from southern Austria and said to be native to that region.

BOTANICAL HISTORY.

The accounts of *Medicago falcata* appearing in old literature are chiefly botanical, and in most cases very brief. However, they are sufficiently clear to indicate that the species was well known, at least to collectors, early in the history of modern botany. The reference cited by Kaspar Bauhin (*8*) and by subsequent botanists as the earliest mention of the species is made by Bock (*10*), who designates his plant as *Melilotus majoris species tertia* and describes it in such a way as to leave a reasonable doubt as to whether it is really *Medicago falcata* or some other species, possibly *Medicago arborea* L. In 1561 Gesner (*24*) published a brief description of it under the name *Trifolii genus medica similis*, mentioning the fact that it has yellow flowers and only slightly coiled pods. This reference may, with a reasonable degree of certainty, be regarded as the first positive mention of *Medicago falcata* in literature, since the identity of Bock's plant is somewhat in doubt. It is true that Kaspar Bauhin (*8*) cited *Trifolii genus medica similis* as a synonym of both *Medicago falcata* and *Medicago lupulina* L., but Gesner's description precludes the possibility of his having the latter species in mind.

By far the best of the early descriptions of *Medicago falcata* is furnished by Clusius (*33*), appearing in 1583. The name *Medica luteo flore*, which he applied, is, in a true sense, a descriptive one, and the description accompanying it treats in considerable detail of the diagnostic characters of the species. Furthermore, a good illustration of the plant, apparently the first one ever published, appears with the description (fig. 2).

Tabernæmontanus (*58*) describes and figures *Medicago falcata* as *Lens major repens*. The description is not convincing, but the figure leaves no doubt as to the identity of the plant. The generic name "Lens" was applied by Tabernæmontanus to various species of Leguminosæ without regard to their relationship.

The name finally chosen by Kaspar Bauhin for the species was *Trifolium sylvestre luteum siliqua cornuta* or *Medica frutescens*. This designation was published in 1623 (*8*).

It was about the time of Johann and Kaspar Bauhin, when the species became the subject of more general study and discussion, that mention of forms that are now known to have been hybrids began to appear in such a manner as to confuse the nomenclature somewhat. It is evident from their writings on *Medicago falcata* that both of the Bauhins fell into errors through their failure to recognize the hybrid nature of the plants which they described.

The name *falcata* was first used in connection with *Medicago falcata* by Rivinus in 1690 (*50*). He used it in a generic sense, dividing what was formerly known as Medica into two groups (Falcata and Cochleata), the distinguishing characters being the degree of twist or coil of the pod. *Medicago falcata* fell in the first division and was designated simply as Falcata. Together with the name, Rivinus published an excellent illustration, which is the first unmistakable figure of a *Medicago sativa* × *falcata* hybrid. Rivinus's name *falcata* in reality applied to the hybrid forms most closely resembling *Medicago falcata.*

In 1694 Tournefort (*59*), following in a general way the classification of Rivinus for the Medica group, took up the old generic name Medica for the plants with screw-shaped pods and coined a new one, Medicago, for those having pods shaped like a collar. Both *Medicago sativa* and *Medicago falcata* were included by him under Medica, the former as *Medica major erectior floribus purpurascentibus* and the latter as *Medica sylvestre.* It is apparent that he intended *Medicago radiata* L. to illustrate the type of his genus Medicago. From his classification it is quite evident that the distinguishing character which Tournefort had uppermost in his mind was the shape of the pod. He was not consistent, therefore, in placing *Medicago falcata* in the genus Medica, since the true form of it does not have the spiral or screw-shaped pod which characterizes his genus. Possibly his knowledge of *Medicago falcata* was confined to the hybrid forms having loosely coiled pods, in which case his arrangement is partially justified.

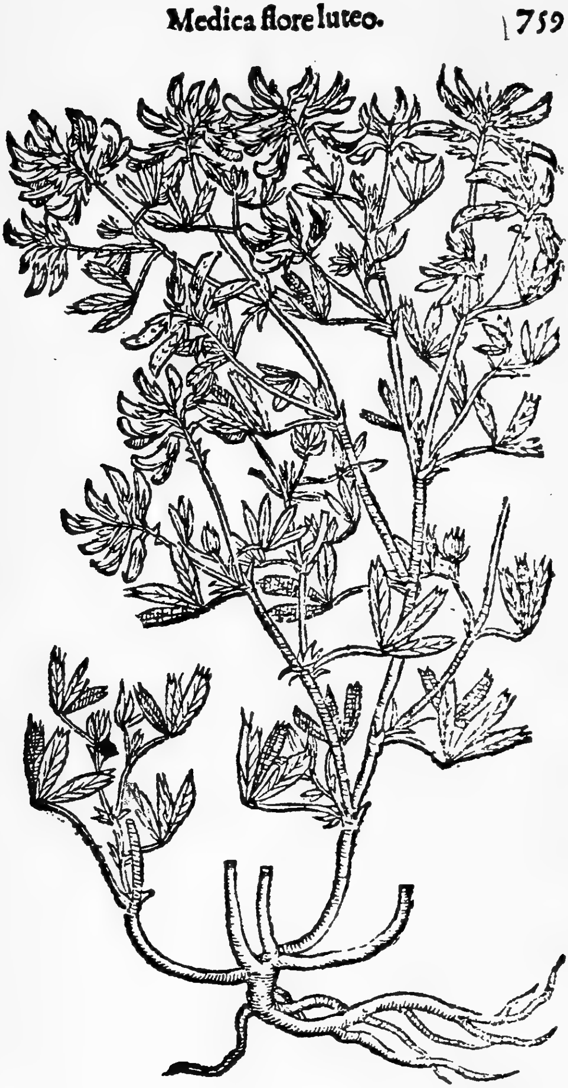

FIG. 2.—Probably the first figure of *Medicago falcata* ever published. Copied from Clusius, Historia, 1583 edition, where it first appeared.

In 1700 Tournefort (*60*) simplified the description of his genera somewhat and added varieties of his *Medica major erectior* (*Medi-*

cago sativa) and also varieties of *Medica sylvestris* (*Medicago falcata*). His varietal classification is based on the color of the flowers, and was doubtless developed from Kaspar Bauhin's description (*8*). It is essentially the same for both species. Tournefort must be given credit for the first attempt at a classification of the varieties of *Medicago falcata*, whatever its value may be, and also for the first botanical usage of the word which was finally to become its generic name.

It was Vaillant (*63*) who placed *Medicago falcata* in the genus Medicago of Tournefort, but it remained for Linnæus to enlarge and define the genus and to assign the name *Medicago falcata* to the species. This he did in 1753 (*40*). A copy of Linnæus's original description of *Medicago falcata* follows; likewise an elaborated outline of the references derived from those accompanying it.

Original description of Medicago falcata.

falcata. 6. Medicago pedunculis racemosis, leguminibus lunatis, caule prostrato. Fl. suec. 620. Dalib. paris. 229.

Trifolium sylvestre luteum, siliqua cornuta. Bauh. pin. 330.

Medica flavo flore. Clus. hist. 2, p. 243. *Habitat in* Europæ *pratis apricis,* siccis. 4.

ELABORATED OUTLINE OF CITATIONS.

[The numbers in italic type refer to "Literature cited," pp. 67–70.]

LINN Sp. Pl. (*40*).

- Fl. suec. 620 [b] (*39*)..
  - Hort. Cliff. p. 377 [b] (*38*)..
    - Riv. tetr.[a] (*50*).
    - Dill. giss. 148 (*19*)..........
      - Riv. Irr. T.[a] (*50*).
      - J. B. 2. 383 [b] (*6*).
      - C. B. 330 [b] (*8*).
    - Dill. gen. 130 (*20*)............
      - D. Rivinus. [a] (*50*).
      - Tournefort [b] (*60*).
    - Bauh. hist. 2. p. 383 [b] (*6*).
    - Tournef. inst. 410 [b] (*60*).
    - Clus. hist. 2. p. 243 [a] (*34*).
    - Moris. hist. 2. p. 157 s. 2. t. 16 f. 1. & s. 2. t. 15 f. 1. (*44*).
      - J. B. Chabr.[b] (*15*).
      - Clus. Hist.[a] (*34*).
    - Bauh. pin. p. 330 [b] (*8*).
  - Bauh. hist. 2. p. 383 [b] (*6*).
    - Taber.[a] (*58*).
    - C. Bauh. phyt. (7).........
      - Trago pag. 591, libr. 2. cap. 3, sineicone [a] (*10*).
      - Clus. histor. Pann. pag. 759, libr. 4, cap. 33 [a] (*33*).
  - Tournef. inst. 410 [b] (*60*)..
    - J. B. 2. 383 [b] (*6*).
    - C. B. Pin. 330 [b] (*8*).
    - Clus. hist. CCXLIII [a] (*34*).
  - Clus. hist. 2. p. 243 [a] (*34*).
  - Bauh. pin. 330 [b] (*8*).
- Dalib. paris. 229 (*17*).
  - fl. suec. 620 [b] (*39*).
  - hort. cliff. 377 [b] (*38*).
  - fl. leyd. prodr. 381 (*52*)..
    - Linn. h. Cliff. 377 [b] (*38*).
    - Riv. tetrap. 84 [a] (*50*).
    - Dill. giss. 148 [b] (*19*).
    - Dill. gen. 130 [b] (*20*).
  - bot. par. (*63*)...........
    - J. B. 2. 383 [b] (*6*).
    - Tournefort (indirectly).
  - Bauh. hist. 2. 383 [b] (*6*).
  - Tournefort—?
- Bauh. pin. 330 [b] (*8*)..
  - Trag.[a] (*10*).
  - Ges.[a] (*24*).
  - Clus. pan. & hist.[a] (*33*).
  - Tab.[a] (*58*).
- Clus. hist. 2. p. 243.[a] (*34*).

[a] No further citations. [b] Elaborated as indicated elsewhere in this outline.

Beginning with the four citations given by Linnæus, the outline indicates the exact manner in which citations are made by various authors, using the abbreviations just as they are found. In many cases the same work is referred to in different ways, which is confusing unless care is exercised in interpreting the abbreviations. A few words of explanation regarding the outline may make it more easily understood.

Linnæus's first citation, it will be noted, is "Fl. suec. 620." In this work are found five citations, the first being "Hort. Cliff. p. 377," which in turn cites eight works, four of which were previously cited in "Fl. suec.," and the first one of which, "Riv. tetr.," makes no further citation, as indicated by the footnote. The others that are not previously cited are further elaborated until works are reached in which no further citations are made. Those that are previously cited are elaborated where they first appear, as, for instance, "Bauh. hist. 2. p. 383," where it appears as a citation of the "Fl. suec." instead of as a citation of "Dill. giss." The outline indicates all the references to *Medicago falcata* that can be traced from Linnæus (*40*) as a starting point.

An examination of the botanical descriptions contained in the works listed in the outline shows very clearly that, while many of the citations refer to true forms of *Medicago falcata*, others refer to hybrid plants and a few confuse *Medicago falcata* and *Medicago sativa.* Following is a classification of the citations, with regard to the plants to which they refer.

Citations that refer to apparently true forms of Medicago falcata.

Linnæus (*39*),[1] Clusius (*33, 34*), Gesner (*24*), Tabernæmontanus (*58*), Kaspar Bauhin (*7*), Johann Bauhin (*6*), Dillenius (*20*).

Citations that refer to what are apparently hybrids between Medicago sativa and M. falcata.

Kaspar Bauhin (*8*), Tournefort (*60*), Rivinus (*50*), Morison (*44*), Chabré (*15*).

Citations that contain only descriptions copied from other authors.

Dalibard (*17*), Royen (*52*), Vaillant (*63*), Dillenius (*19*).

Citation in which Medicago falcata and M. sativa are apparently confused.

Linnæus (*38*).

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[1] The numbers in italic type refer to "Literature cited," pp. 67–70.

BOTANICAL DESCRIPTION AND RELATIONSHIP.

BOTANICAL DESCRIPTION.

The description of *Medicago falcata* given by Linnæus in 1753 (*40*), when the binomial was first published, merely indicates that the peduncles are racemosely arranged, that the pods are crescent shaped, and that the stems are prostrate in habit of growth. This, as a matter of fact, can scarcely be considered as a description, since it is in reality only a part of an analytical key to certain species of the genus Medicago. Various descriptions, however, have appeared since that of Linnæus. A fairly good one was published by Lamarck in 1789 (*31*) and another by Martyn in 1792 (*43*).

The difficulty of preparing a satisfactory description becomes at once apparent upon consideration of the numerous forms of the species. Many of the early ones are confusing because their authors failed to recognize the existence of hybrids among the forms which they attempted to describe, and all of them are imperfect, since in no place was a complete collection of the forms of the species available. Even at this time, with the work of others from which to draw and with the abundant material at hand, it is far from easy to prepare a description that will present a comprehensive view of the species. The diversity of *Medicago falcata* inspires the investigator at once with the desire to attempt a classification that will fit all existing forms. However, it requires only a little investigation to convince one of the hopelessness of such a task.

In the main there are two difficulties in the way of developing a satisfactory scheme of classification—the lack of consistency in the combinations of characters and the practical impossibility of determining from one generation of plants whether a form is of pure or hybrid origin. There is, however, a certain correlation of characters which permits a general grouping, although intergrading forms are so common that it frequently is difficult to differentiate the mass even into broad groups.

To serve as a basis for further discussion of botanical characters it seems advisable, first, to present some rather detailed data, including observations and careful measurements made in connection with the study of a large number of plants secured from many sources, these constituting a composite description of the species. Following these data an attempt is made to correlate certain characters and to define the principal groups and describe them in the abstract. It is hoped that this method of treatment, together with illustrations reproduced from photographs, will convey a reasonably clear idea of the appearance of the striking forms of *Medicago falcata*.

COMPOSITE DETAILED DESCRIPTION.

The flowers of the numerous forms of the species vary considerably in color, size, and shape of banner, length of calyx teeth, and slightly in length of calyx tubes. There is also a variation in the length of pedicels, the number and compactness of the racemes, the number of flowers in the raceme, and the date of blooming. In color the flowers range from a light yellow to a deep chrome yellow, the pale yellow color being the most prevalent in the individuals that more nearly approach *Medicago sativa* in general appearance.

On the steppes of northern Russia and Siberia occur forms that have variegated flowers. These forms are found apparently remote from forms of *Medicago sativa* and so closely associated with forms of *Medicago falcata* having pure yellow flowers that Prof. Dilitwinoff,[1] of the Academy of Sciences, Petrograd, is of the opinion that they are true forms of the latter. Meyer, however, who has studied them in their native habitat, believes them to be hybrids of *Medicago sativa* and *Medicago falcata*, and a study of the progeny of these plants grown from the seed collected by the department's explorers indicates quite definitely that Meyer's opinion is well founded. The progeny exhibits a diversity of forms, some of which closely resemble *Medicago sativa*, while others present the appearance of true *Medicago falcata*. But regardless of this, the wild variegated forms are regarded with interest in connection with the study of the origin of the cultivated alfalfas and the botanical relationship existing between the above species.

Flowers.—The individual flowers of *Medicago falcata* are smaller than those of *Medicago sativa*. The lines which mark the banners are shorter in the former than in the latter and are light to dark brown, varying directly with the color of the flower. A large number of careful measurements show that the banners vary from 6.25 to 12 mm. in length and from 2.20 to 8 mm. in width. The ratio of length to width of the banner also varies, ranging from approximately 1.2 to 1 to 3 to 1. The calyx averages about 1.75 mm. in length and varies from approximately 1.3 to 2.6 mm. There is a greater variation, however, in the length of the calyx teeth, the range being from 1.25 to 3.75 mm. The pedicels are from 1.25 to 3.75 mm. in length.

There appears to be little uniformity in the number of flowers in the raceme. In some cases as few as five are found, while in others as many as 36 may be present. Racemes with the largest number of flowers have been noted to be compact and of medium size. The very fine leaved plants and the plants with long procumbent stems have small racemes, with comparatively few flowers. Likewise, the

[1] In letter on file in the United States Department of Agriculture.

very large ascending plants with long, erect stems, as well as the broad-crowned forms, have few flowers to the raceme. The upright bushy plants with stiff stems and narrow greenish gray leaves have, in general, the largest racemes. A great abundance of flowers does not appear to be characteristic of any special form of the species. The compactness of the raceme is dependent to a large extent on the length of the pedicel, the size of flower, and the arrangement on the axis. Compact racemes are usually small, and the flowers are arranged at more regular intervals than they are in the loose racemes.

The flowers of *Medicago falcata* usually come into bloom earlier than those of *Medicago sativa.* However, the broad-crowned procumbent to decumbent plants of the former are especially late in blooming. The flowering period is much longer than in the case of *Medicago sativa*, frequently extending from May to October in South Dakota.

Pods.—The pods vary greatly in proportion of width to length and range in shape from almost straight to semicircular or more

FIG. 3.—The common types of pods of *Medicago falcata.*

nearly coiled, even in what appear to be pure strains of the species. The average pod is crescent or sickle shaped, reticulate veined, without glandular hairs, but in some cases slightly pubescent. When mature they are light brown to almost black in color. (Fig. 3.)

On pod characters it is possible to distinguish two fairly distinct types of plants. Type 1.—Pods short, broad in comparison to length, of medium thickness, nearly straight, and pointed. Pods of this type are light brown to dark brown in color, dehisce readily upon approaching maturity, and on the average contain one less seed than the average for the species. They are confined almost exclusively to the more nearly erect stiff-stemmed types of plants and are found abundantly in S. P. I. Nos. 20721 and 20722. They are well illustrated by pods Nos. 8, 9, and 10 in the top row of figure 3. It was to plants having pods of this general form that the varietal name stenocarpa (Reich.) (*49*) was apparently intended to apply. Type 2.—Pods long, narrow in proportion to length, sickle shaped to nearly coiled, brown to almost black in color. The general type is illustrated by pods Nos. 7, 8, 9, and 10 in the second row of figure 3. This is a distinct type of pod and is found most abundantly in plants having medium broad crowns and long and decumbent to ascending stems, as shown in figure 13. They are found in S. P. I. Nos. 20726, 26927, and 30433. The number of seeds per pod averages approximately one more than the average for the species. The seeds are well retained, and the pods are quite plentifully produced. Plants bearing pods of this type set seed more liberally than other forms of the species. It must be understood that the two types of pods above described represent the extremes and that there are many intermediate forms.

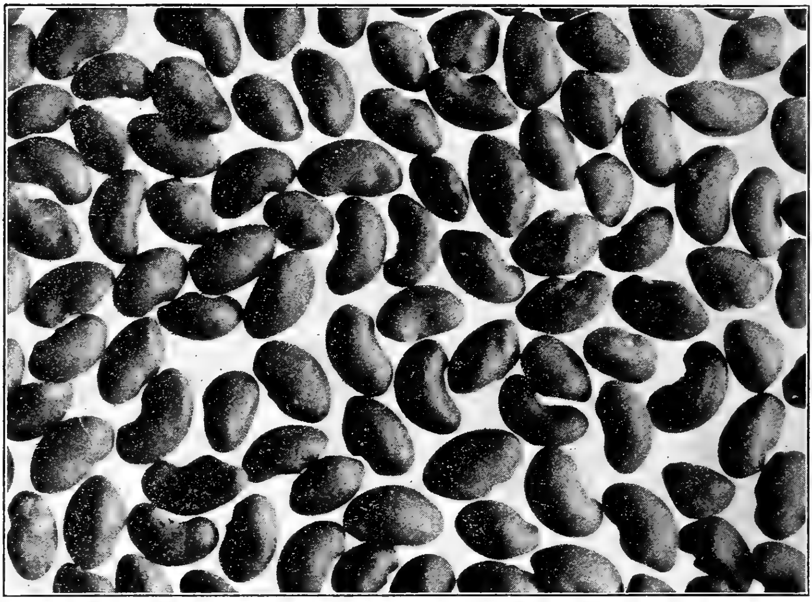
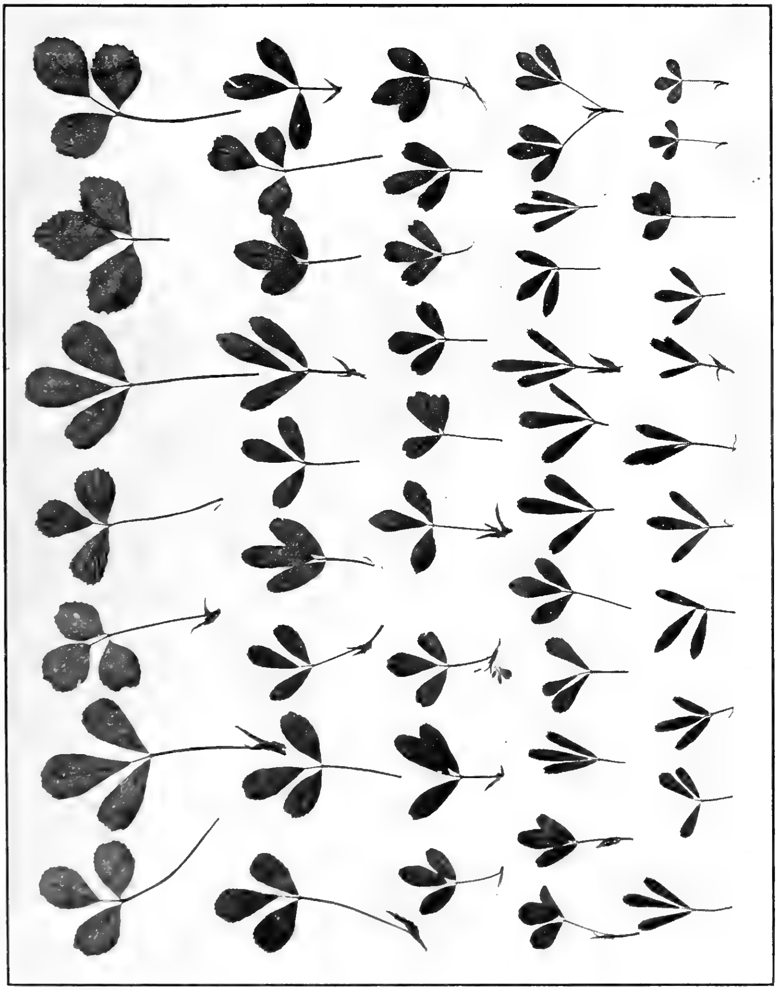


FIG. 4.—Seed of *Medicago sativa*. (Enlarged.)

Seeds.—In general appearance the seeds closely resemble those of *Medicago sativa* (fig. 4), but a careful examination shows them to be appreciably smaller and decidedly more angular. The radicle is also more prominent and in some seeds the hilum is very marked, while in others it is scarcely apparent. (Fig. 5.) When examined under a lens the seeds show a slightly roughened surface. The pitted surface together with the angular shape produces a feeling of grittiness when seeds are rubbed between the thumb and fingers. This is especially true of seeds from certain forms of plants.

The explosive mechanism of the flower is essentially the same as that of *Medicago sativa*, with the exception that more force is required to accomplish tripping and usually less energy is expended by the column upon becoming released. This condition, together

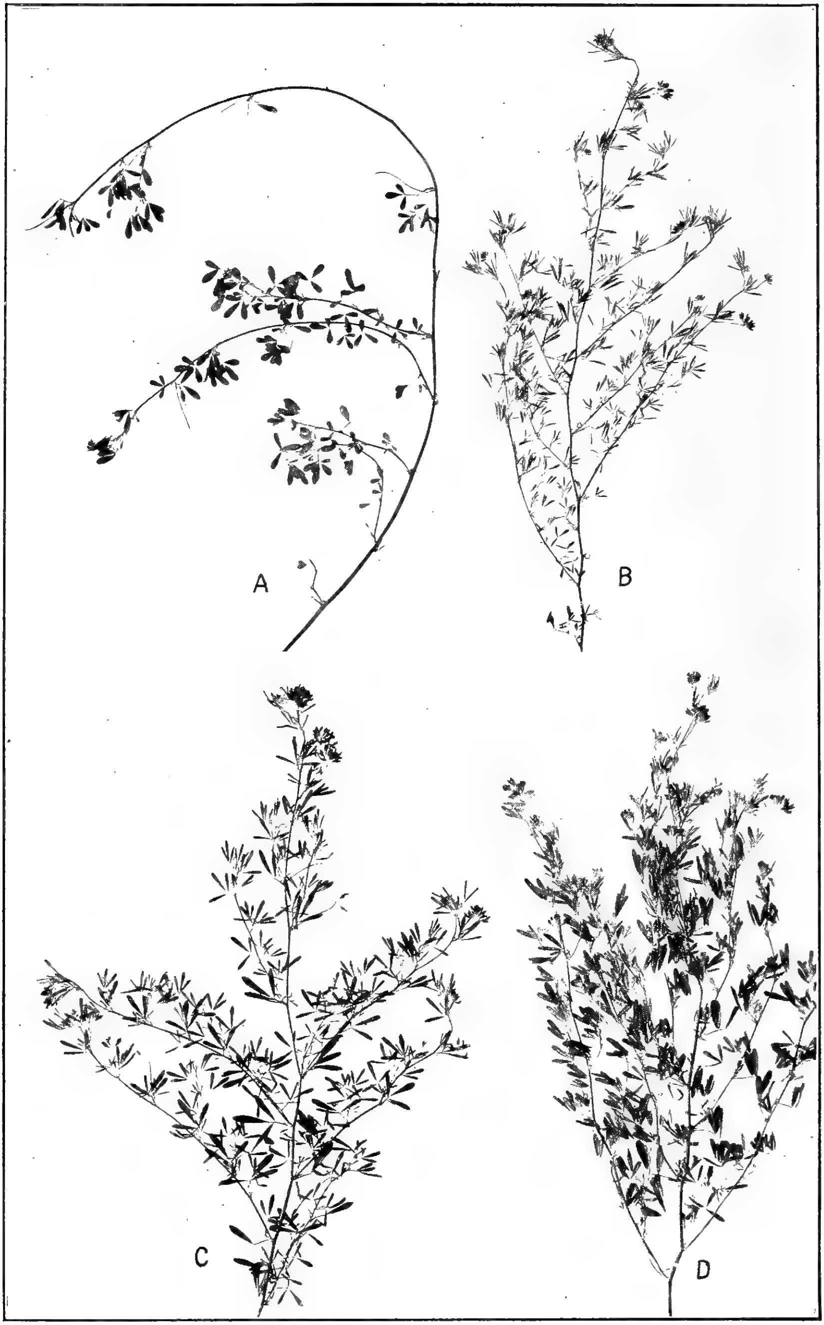


LEAVES OF MEDICAGO FALCATA.

The numerous forms of the species present great variations in the size and shape of their leaves.

STEMS OF MEDICAGO FALCATA—I.

STEMS OF MEDICAGO FALCATA—II.



STEMS OF MEDICAGO FALCATA—III.

with the scanty production of pollen in the case of many of the flowers, may be responsible to some extent for the paucity with which the seed of the species is produced.

Leaves.—The leaves vary in shape from ovate to linear-cuneate. (Pl. I.) The type and stage of growth of the plant and the position in which the leaves are borne on the stem all influence their size and shape. During the first few weeks of growth in the spring they are larger and more ovate than they are later in the season. They also appear to diminish in size and become more elongated as the end of the stem is approached. In general, they are more elongated or linear than those of *Medicago sativa*, although there are some

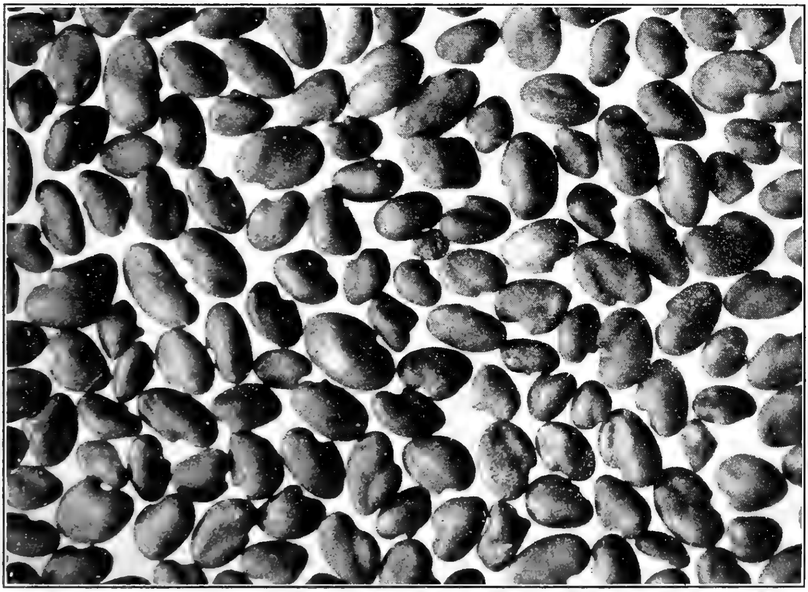


FIG. 5.—Seed of *Medicago falcata*. Note the prominence of the radicle and the roughness and irregularity as compared to those of *Medicago sativa* (fig. 4). (Enlarged.)

marked exceptions, as will be noted in the illustration. A series of measurements indicates the range of proportion of length to width to be from 1.8 to 1 to 16 to 1. The more ovate leaves are common in groups of plants represented by S. P. I. Nos. 24454 and 20725 (Pls. II, *C* and *D*, and III, *A* and *C*), while the more linear leaves are abundant in the group represented by S. P. I. Nos. 20718 and 24455 (Pls. II, *A* and *B*, and IV, *B* and *C*). The large leaflets are approximately 27 mm. long by 12 mm. wide, and the smaller ones approximately 9 mm. long by 1.5 mm. wide. The plants having the larger leaflets approach *Medicago sativa* in general characteristics. The margins of the leaves are more or less serrate; the apex deeply notched, mucronate, or in some cases nearly entire. In some leaves the midrib forms a ridge, while in others it is decidedly depressed, being almost buried in the fleshy tissue. Prominent midribs are usually of a brownish color and occur in elongated and frequently quite pubescent leaves. The veins of the leaves are more nearly parallel than they are in *Medicago sativa* and are more symmetrical in the linear than in the obovate type. The color of the leaves varies from a greenish yellow to a dark bluish green, the quantity of pubescence affecting the color to a considerable extent. An abundance of pubescence which produces a greenish gray effect is especially noticeable on plants that have deeply notched leaves, such as are found in S. P. I. Nos. 20721 and 20722. Upon drying, the leaves of certain forms develop an almost indigo-blue color.

The abundance of leaves appears to be correlated somewhat with shape, sparseness of production being found in plants where the narrow type of leaf is predominant. Supernumerary leaflets are much more common than in *Medicago sativa*, the number of leaflets frequently reaching five in certain forms, while, on the other hand, two leafllets are very common in some forms.

The petioles are far from uniform in length and the stipules vary in shape from broadly triangular to linear, their margins varying from deeply serrate to almost entire.

Stems.—To only a limited extent are the stem characters correlated with plant type. There are some cases, however, where a correlation exists with a fair degree of consistency. In the broad-crowned forms, as found in S. P. I. Nos. 20717 and 20725, the plants have uniformly slender stems of greatly varying length. In the ascending forms, as found in S. P. I. Nos. 20721 and 20722, the stems are stiff and of medium size, while in certain decumbent plants fairly stiff trailing stems are found, some reaching 4 feet in length. These are common in plants of S. P. I. Nos. 24452 and 24454. Long, slender stems are abundant in broad-crowned, procumbent forms, as found in S. P. I. No. 24454. The plants of the bushy habit commonly have short stems. The procumbent to decumbent plants have twisted, irregular stems, while the stems of bushy plants are usually more regular and more nearly straight.

The number of stems is greatest in the broad-crowned plants and ranges in some cases from approximately 1,600 per plant in plants of this character to 300 or less in the narrow-crowned ascending forms. These data are based on plants 4 years old. Some of the stems are quite pubescent, while others are smooth. They vary from numerous shades of green to reddish brown, the color being more of a fixed characteristic than the result of seasonal conditions. A very good idea of the variation in the stems of *Medicago falcata* and also some conception of its racemes and leaves can be gained from an examination of Plates II, III (*B*, *C*, and *D*), and IV.

Roots.—*Medicago falcata* differs to a considerable degree from *Medicago sativa* in having a much more branching root system. In comparatively few cases is a single taproot developed, while the entire absence of the taproot proper is very common. In the majority of plants, however, there is a tendency toward the development of a much-branched taproot and a large number of small lateral roots. Meyer reports taproots of remarkable size on wild plants growing on the sandy banks of the Tom River, near Tomsk, Siberia. Some of these large roots were more than 2 inches in diameter at the crown and more than 1 inch in diameter at a depth of 14 feet; a few of them extended to a depth of more than 33 feet. Such a taproot develop-

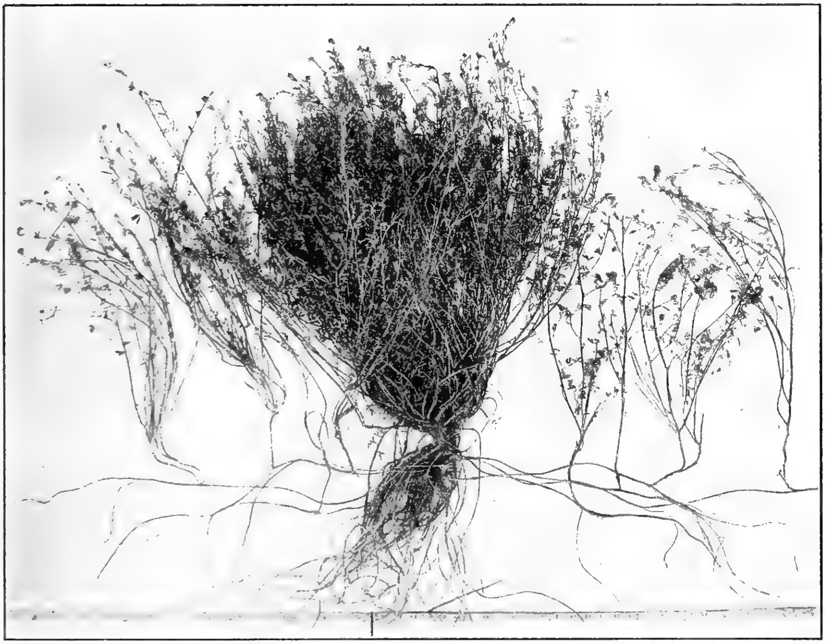


FIG. 6.—*Medicago falcata*, S. P. I. No. 28071, a 3-year-old plant grown at Highmore, S. Dak. Note the new plants that have developed from true lateral roots.

ment, however, is very uncommon in the species and occurs only in sandy or loose soils. A peculiar root system characterized by a branched taproot from which horizontal lateral roots are produced is found in some forms. The lateral roots give rise to aerial shoots, which develop ultimately into perfect and in some cases independent plants. (Fig. 6.) This type of proliferation has been previously described by the writers (*45*). It does not appear to be correlated with general habit of growth or with any important plant characters, although, as far as has been observed, it is not found in plants of the very low spreading habit. It is common in S. P. I. Nos. 24455, 28070, 28071, and 23625. The first two of these numbers were introduced from Semipalatinsk, Siberia, and the last two from Orenburg, Russia. Root systems of similar character are found in *Rhus glabra* L., *Ambrosia psilostachya* DC., *Cirsium undulatum* (Nutt.) Spreng., *Convolvulus arvensis* L., *Ipomoea leptophylla* Torr., and numerous other species. The development of proliferating roots in certain forms of *Medicago falcata* presents a rather interesting situation from a taxonomic standpoint. So far as the writers are aware, there are no other species having two forms, one in which this character is present and the other in which it is absent.

The tendency to produce rooting rhizomes permits the development of a much more extensive root system than is ordinarily found in *Medicago sativa.* It is characteristic of many of the roots of *Medi-*

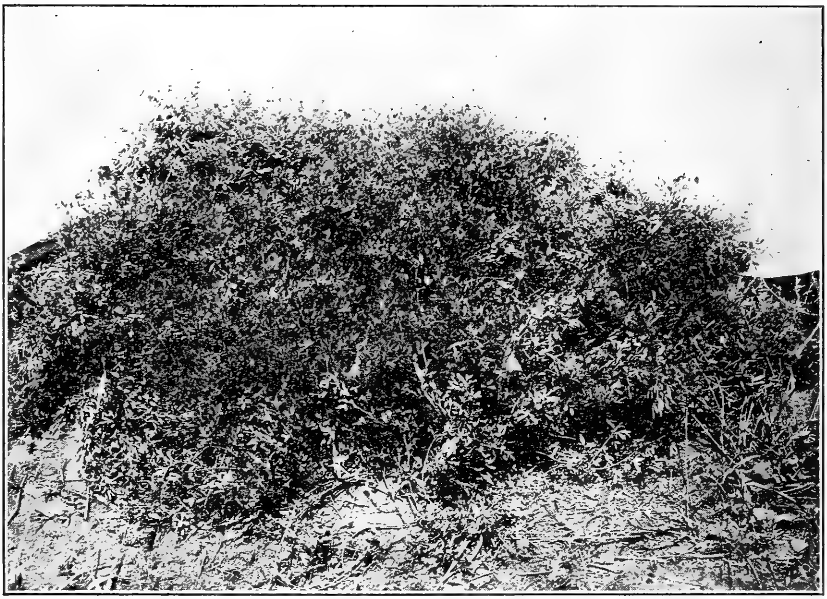


FIG. 7.—Individual plant of *Medicago falcata,* S. P. I. No. 20717, typical of the forms included in Group I.

cago falcata that they possess the ability to produce new plants if cut off at the surface of the ground or if they become exposed accidentally.

GROUPS.

A division of the forms of *Medicago falcata* into groups may be made on the basis of several characters; for example, color, size, and abundance of flowers, type of pod and seed habits, foliage characteristics, stem types, and even root systems to a certain extent. From a strictly botanical standpoint a classification on one or more of these sets of characters would appear to be desirable, but the combinations of characters in the plants are such that a logical grouping along these lines can not be made. In order to include in the same class the forms that most naturally resemble each other, it seems necessary to make the divisions along the line of plant type with regard to erectness, type of crown, and general habit of growth. A classification even on this basis has in it many inconsistencies, not only with regard to special botanical characters, but also in the general characteristics upon which it is founded. Its weaknesses from a botanical standpoint are fully appreciated, yet it seems to be less artificial than the other classifications that suggest themselves. It possesses the additional advantage of being based on characters of agronomic im-

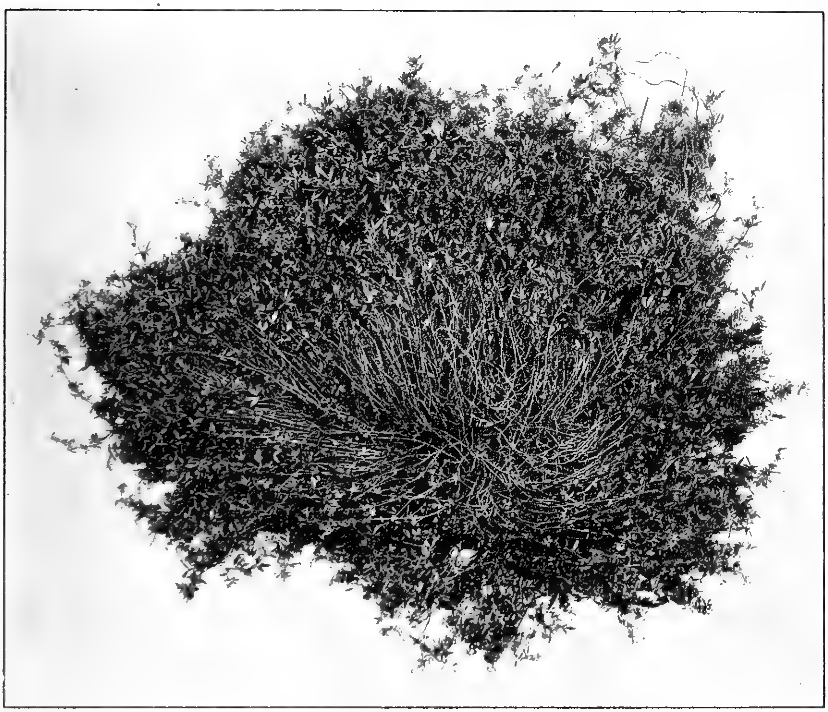


FIG. 8.—Individual plant of *Medicago falcata*, S. P. I. No. 20725, as viewed from directly above; a very procumbent, fine-stemmed form, illustrating Group I.

portance; in fact, it is perhaps more agronomic than botanical, and is certainly more in the nature of a convenient grouping than an outline of actual relationships. It is hoped that a further study of the material will result in the development of a more satisfactory classification.

The system which is adopted herein provides for four groups. Certain of these are pretty clearly defined, while some differ from others only in degree. Each group is illustrated by a figure of an individual plant, and for the benefit of those to whom the department's introductions of *Medicago falcata* are available S. P. I. numbers are cited, which include forms that are typical of the groups.

It will be noted that in certain cases numbers are referred to under more than one group. This is explained by the fact that many of the introductions as they were received from abroad contained several forms of the species. The descriptions given under each group are brief, but they are as full as the nature of the material warrants. The types or groups are as follows:

GROUP 1.—*Prostrate.*—Plants of this group are characterized by broad to very broad crowns, which have a tendency toward the development of barren centers after two or three years. (In many cases 4-year-old plants have crowns 36 inches in diameter.) The plants are of prostrate or procumbent habit of growth and are decidedly spreading. The leaves are about average in size and shape, but in the more narrow crowned plants are inclined to be of a darker color than the average for the species. The flowers are of a deep yellow color and inclined to be small, late blooming, and some-

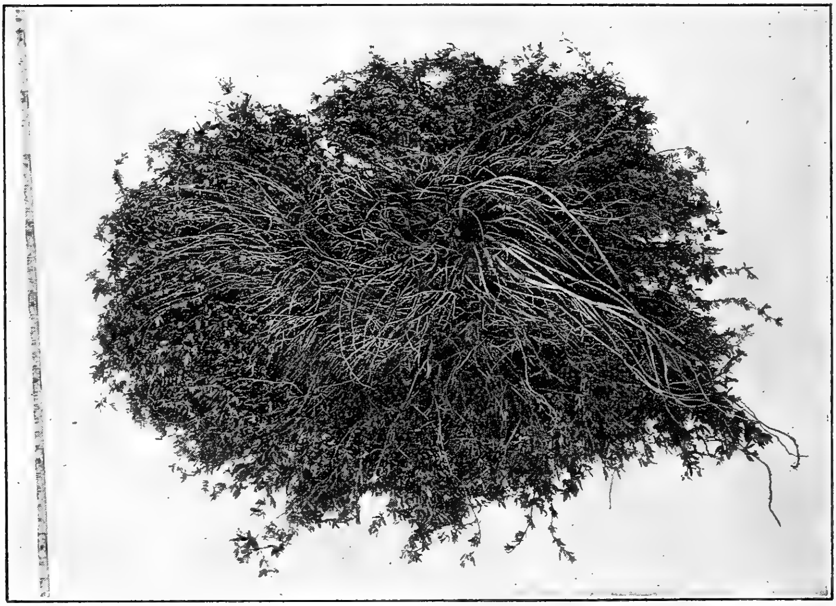


FIG. 9.—Individual plant of *Medicago falcata,* S. P. I. No. 20725, as viewed from beneath. The small whitish stems are rhizomes.

what scantily produced. The seed is produced scantily or only fairly abundantly. In the extremely broad crowned plants the stems are numerous (as many as 1,600 per plant in plants 4 years old), and individual plants having fine, short stems are common. In the more narrow crowned plants, the stems are inclined to be long and fine and less numerous than in the very broad crowned forms (approximately 300 in plants 4 years old). Plants representing this group are common in S. P. I. Nos. 20717, 20725, and 24454 and are well illustrated in figures 7, 8, and 9.

GROUP 2.—*Decumbent.*—Plants of this group have medium broad crowns, which frequently become barren at the center at the end of a few years. (Crowns of 14 inches in diameter are common in 4-year-old plants.) Habit of growth, decumbent to procumbent; flower, pod, and seed characters variable; the racemes are inclined to be compact; stems of medium length, inclined to be long; leaves not especially abundant. This type of plant is common in S. P. I. No. 24452 and is illustrated in figures 10 and 11.

GROUP 3.—*Ascending.*—Plants of this group have medium broad crowns, with an average diameter less than those in group 2. Habit of growth, ascending. No striking characteristics are found generally in their flower or seed habits. Stems rather coarse, inclined to be crooked, and not especially abundant; leaves usually not abundant. This type is found quite commonly in S. P. I. Nos. 20718, 20719, 24455, 28070, and 28071 and is well illustrated in figures 12, 13, and 14.

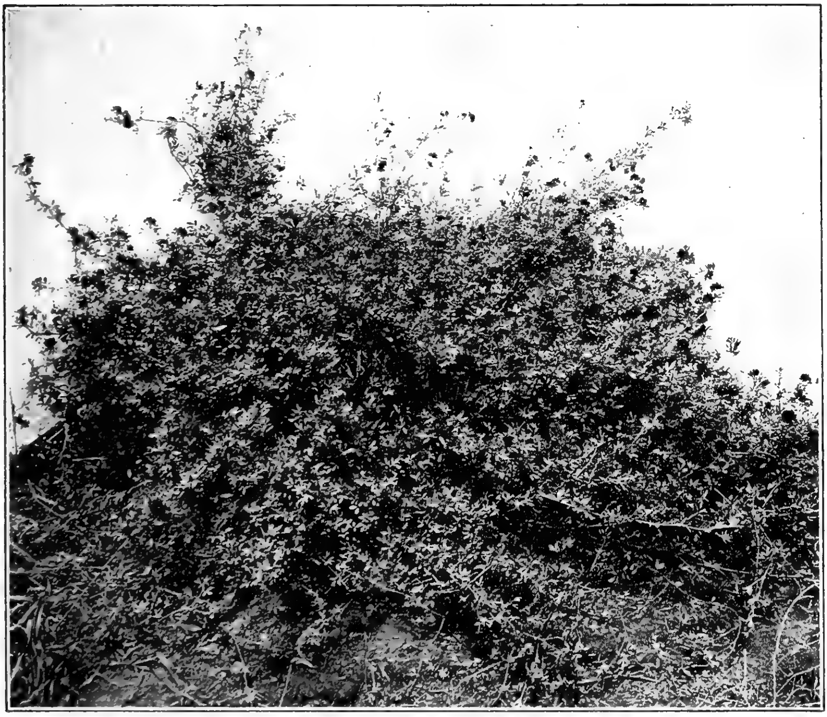


FIG. 10.—Individual plant of *Medicago falcata,* S. P. I. No. 24452, a broad-crowned plant with long procumbent to decumbent stems, representing Group II.

GROUP 4.—*Suberect.*—Plants of this group have medium to small crowns and are ascending to erect in habit of growth. They are not characterized by special flower types, but in general produce seed sparingly. The stems are stiff and the leaves approach those of *Medicago sativa* in shape, but are smaller and more abundantly produced. This type of plant is found in S. P. I. Nos. 20718, 20719, 24455, 28070, and 28071, but not abundantly. It is well illustrated in figures 15 and 16.

There are many forms that do not fit perfectly into the above groups but fall in the zones between the groups, since they have combinations of characters that are not consistent with this classification. However, the four groups described, if interpreted liberally, can be made to cover a large majority of the forms of the species so far obtained. From an agronomic standpoint, groups 1 and 2 represent plants which in their pure state may be considered of value only for pasturage on account of their procumbent tendencies, while groups 3 and 4 are sufficiently erect to be utilized for the production of hay. For convenience these groups may be referred to as pasture and hay groups, respectively.

BOTANICAL RELATIONSHIP.

Considerable difference of opinion exists among botanists as to the exact relationship which *Medicago falcata* bears to the group of Medicagos commonly referred to as alfalfas. By many it is given a specific rank coordinate with *Medicago sativa*. By others it is

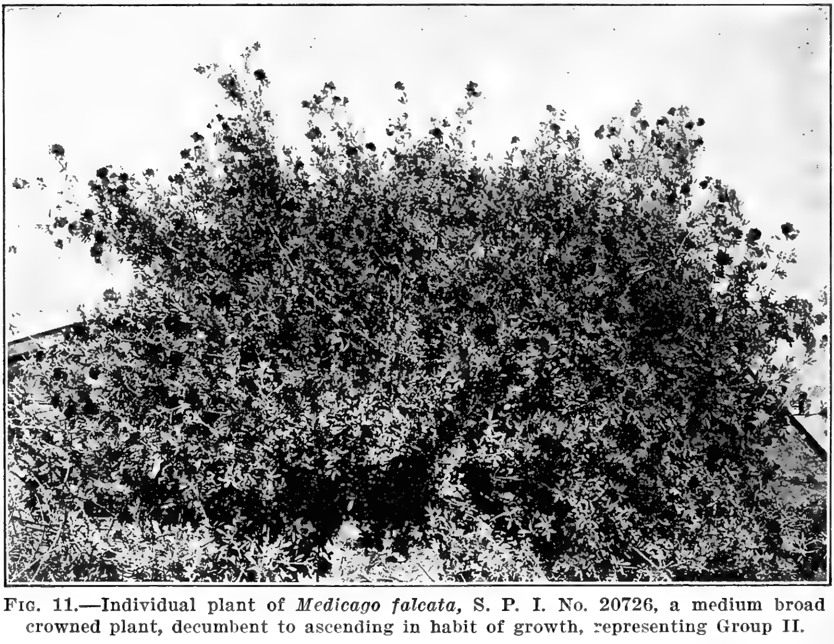


FIG. 11.—Individual plant of *Medicago falcata*, S. P. I. No. 20726, a medium broad crowned plant, decumbent to ascending in habit of growth, representing Group II.

regarded as a subspecies of *Medicago sativa*, while some are of the opinion that *Medicago falcata* is the true species and that *Medicago sativa* is only a subspecies or a cultivated variety of it. Linnæus (*38*, *39*) at one time suggested the latter arrangement.

Urban (*62*) divides *Medicago sativa* into two sections, "*Macrocarpa*" and "*Microcarpa*," and places *Medicago falcata* under the former, coordinate with *vulgaris*, which he indicates is the common cultivated variety of *Medicago sativa*.

Alefeld (*1*) designates common alfalfa as *Medicago sativa vulgaris* and *Medicago falcata* as *Medicago sativa falcata*.

Ascherson and Graebner (*2*) follow essentially the classification of Urban, but Rouy and Foucaud (*51*), Seringe (*57*), and many other botanists class *Medicago falcata* as a distinct species coordinate with *Medicago sativa.*

While opinions differ as to the relationship of *Medicago sativa* to *Medicago falcata*, the natural relationship is clearly indicated by the frequency and fertility of the hybrids between the two. With the exception of the forms of Medicago which Urban (*62*) assigns to *Medicago sativa* and *Medicago prostrata* Jacq. (*28*) there are no others so far reported that hybridize naturally with *Medicago sativa*—and but few that can be crossed artificially.[1]

These facts are especially significant in the Leguminosæ, where hybrids of any kind are extremely rare. A careful study of the behavior of the hybrids of *Medicago sativa* and *Medicago falcata*

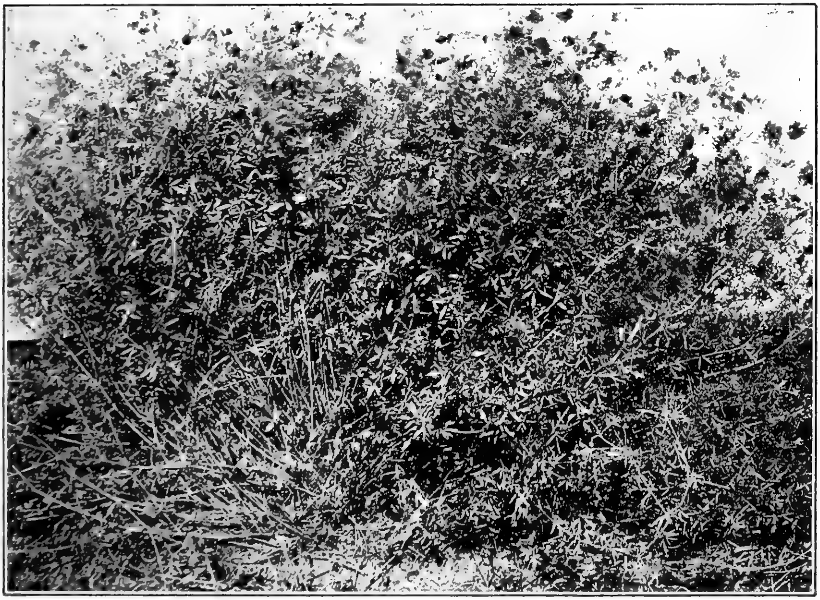


FIG. 12.—Individual plant of *Medicago falcata,* S. P. I. No. 28070, a medium broad crowned plant of ascending habit of growth, representing Group III.

points to a common origin of the parents at no very remote date in their evolutionary history. Regardless of the somewhat contradictory opinions that exist, *Medicago falcata* will be referred to throughout this paper as a true species.

Botanical names have been assigned to what appear to be true forms of *Medicago falcata* and both specific and varietal names to forms that are apparently hybrids of *Medicago falcata* and *Medi-*

[1] Hybrids of *Medicago sativa* and *Medicago prostrata* have been reported by Ascherson and Graebner, but there is a much closer relationship between these species than Urban's classification would indicate. Numerous broad crosses of legumes have been reported, including one of *Medicago sativa* and an annual or biennial species of the same genus, but they are all of doubtful authenticity.

cago sativa. In the latter instance the names were applied in many cases without knowledge of the hybrid nature of the plants. There is very little justification for the attempts that have been made to describe and name forms of true *Medicago falcata*, since the characteristics of these forms to which names have been applied are neither definite nor consistently correlated with other important characters. There would appear to be no justification for the attempts to name and describe unstable hybrids. Tournefort (*60*) was the first to do this, but he was not aware that the forms with which he dealt were hybrids. More recent botanists likewise have apparently failed to appreciate this fact with regard to material com-

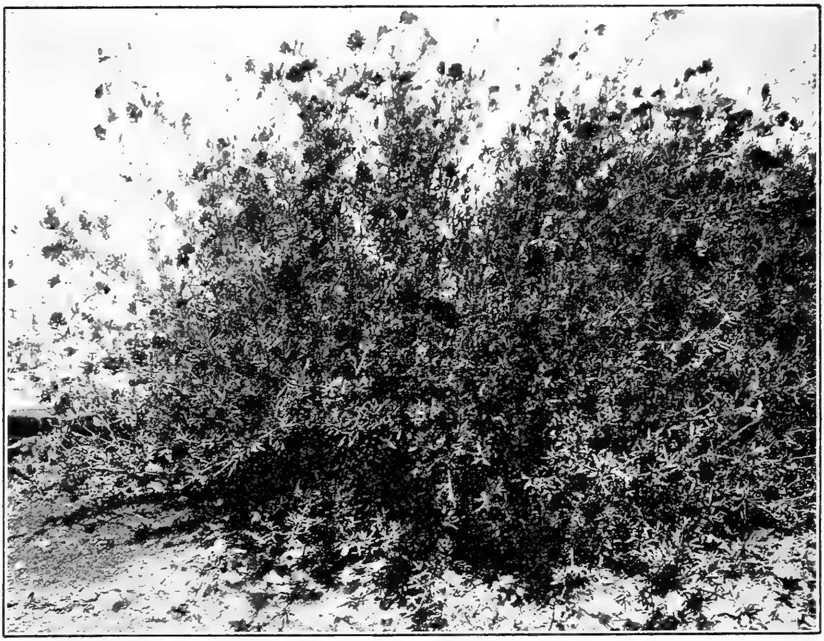


FIG. 13.—Individual plant of *Medicago falcata*, S. P. I. No. 24455, a medium broad crowned plant of ascending habit of growth, representing Group III.

ing under their observation, as otherwise they doubtless would have refrained from describing hybrids as species or varieties.

It has been possible to find among the department's introductions and selections forms that answer to the description of most of the varieties of *Medicago falcata* and *Medicago sativa* that have been proposed by botanists. That many of these forms are hybrids is quite clearly indicated by the fact that their progeny even from one generation of self-fertilized seed breaks up in a manner characteristic of hybrids. Furthermore, certain of the so-called varieties have been created as a result of artificial crossing, and there is abundant reason to believe that a great many of them can be originated in this way. The extensive living collection of alfalfas which the department has in its possession furnishes an opportunity for studying the variations that is not afforded by the herbaria of the country and makes it possible to gain a conception of the group as a whole that can not be gained from a study of dried material.

Partial lists are given here of the botanical names that have been applied to what appear to be forms of true *Medicago falcata*, to hybrids of *Medicago falcata* and *Medicago sativa*, and to species and varieties whose origin and relationship to *Medicago falcata* are not clear, together with a brief description of the forms in question. The localities in which the various forms were collected are in most cases indicated in the descriptions.

FIG. 14.—Individual plant of *Medicago falcata*, a somewhat coarse stemmed, ascending form, probably introduced from India, representing Group III.

Botanical names that have been applied to what are apparently true forms of Medicago falcata.

M. procumbens Bess. (*9*).[1]

Pods falcate, nearly smooth; stipules dentate at the base; leaflets oblong, dentate at the apex; stems procumbent; flowers golden; mature pods falcate. Locality: Lemberg and Cracow.

M. intermedia Schultes (*54*).

Stems procumbent; peduncles corymbose-racemed; pods falcate, slightly pubescent; stipules sagittate; leaflets linear, obcordate, apex slightly serrulate; flowers yellow. Locality: Galicia.

M. falcata pratensis Boenn. (*11*).

Diffuse; leaflets linear-cuneate, narrow, clearly dentate at the apex, truncate; racemes short. Locality: Munster, Germany.

[1] The numbers in italic refer to "Literature cited," pp. 67–70.

M. falcata riparia Boenn. (*11*).

Stems large, erect; leaflets very large, oblong, dentate at the apex, slightly truncate; racemes elongated, many flowered; flowers large. Locality: Munster, Germany.

M. falcata montana Boenn. (*11*).

Stems slender, filiform, decumbent; leaflets small, linear-truncate, slightly dentate; racemes few flowered, capitate; flowers one-half as large as *M. falcata pratensis.* Locality: Munster, Germany.

M. falcata minor Gaud. (*22*, p. 611).

Pods falcate or once coiled. Locality: Vicinity of Sierre, Switzerland.

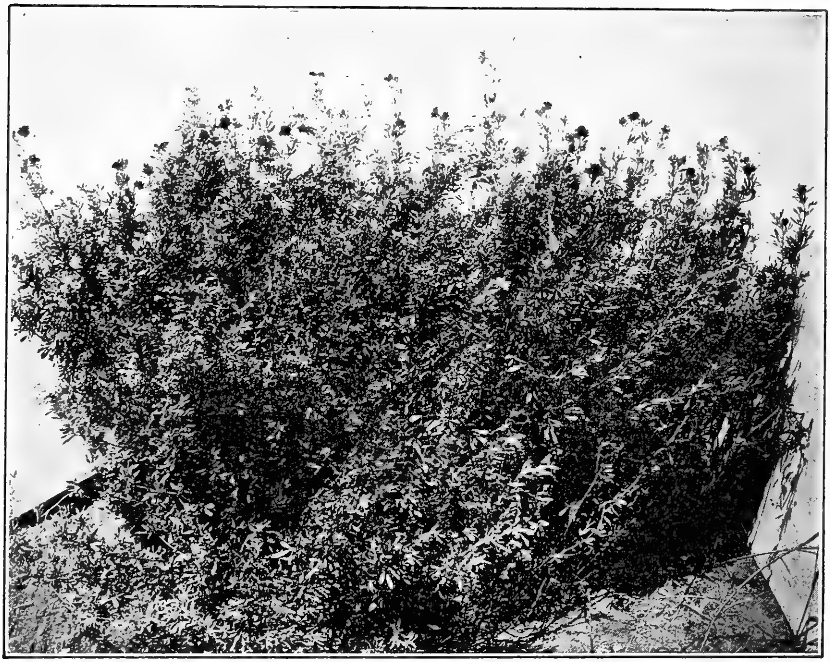


FIG. 15.—Individual plant of *Medicago falcata*, S. P. I. No. 20719, a form of very leafy, erect habit, very desirable from a forage standpoint, typical of Group IV.

M. falcata stenocarpa Reich. (*49*).

Pods semicircular, narrower than those of ordinary *M. falcata*, diameter of the arc 3 lines, width 1 line. Locality: Not specified.

M. falcata major Koch (*29*, p. 160).

Stems elongated, procumbent; stipules larger than those of ordinary *M. falcata* and more dentate. The author cites *M. procumbens* Bess., and *M. intermedia* Schultes, as synonyms. Locality: Not specified.

M. falcata major prostrata Koch (*30*).

Stems 2 feet long, prostrate; stipules strongly toothed; flowers proportionately large and bright yellow. Locality: Germany.

M. falcata procumbens Ledeb. (*35*).

Stems long, prostrate; stipules foliaceous, semisagittate; flowers larger than those of ordinary *M. falcata;* pods less arched, more unequal, almost smooth. Locality: Volhynia, Podolia, and Bessarabia, Russia.

M. falcata genuina Godron (*25*).

Flowers vivid yellow; pods falcate. Locality: Environs of Nancy, France.

M. falcata typica Trautv. (*61*).

Flowers yellow; pods falcate or semicircular. Locality: Ajagus, Siberia.

M. falcata diffusa Schur (*55*).

Stems slender, diffuse; secondary branches short, erect; leaflets very small, obovate-oblong; flowers smaller than those of *M. falcata major* of Koch, yellow; pods falcate, smooth. Locality: Salzburg and Kolos, Hungary.

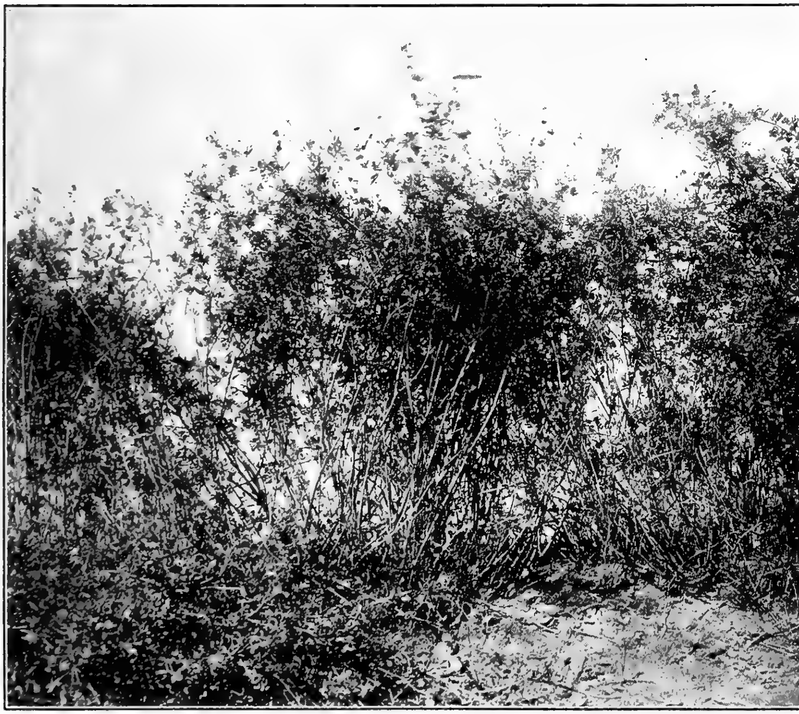


Fig. 16.—Individual plant of *Medicago falcata*, S. P. I. No. 30433, a very upright, somewhat coarse form which can be easily harvested by the ordinary hay machinery, representing Group IV.

M. falcata alpignea Schur (*55*).

Slightly shrubby, very branching; leaflets very small, obovate, mucronate at apex; pods semicircular or falcate, slightly pubescent. Locality: Transylvanian Alps.

M. sativa falcata Alefeld (*1*, p. 75).

Stems prostrate; leaflets ½ inch long by 2½ lines broad; flowers yellow; pods falcate to nearly circular, making from one-fourth to 1 coil. Locality: Germany and Austria.

M. falcata suberecta Lindm. (*37*).

Stems ascending, erect; pods falcate or semicircular. Subvar. 1.—Smoother, leaves broader. Subvar. 2.—More hairy, leaves narrower. Locality: Elizavetgrad, Russia.

M. falcata microphylla Cusin and Ans. (*16*).
No description is given of this plant, but judging from the illustration it is very slender; apparently prostrate; leaflets small, narrow, truncate, toothed at the apex; pods rather broad, falcate or nearly straight. Locality: Not specified.

M. falcata gracilis Urban (*62*, p. 56).
Racemes 1 to 5 flowered; leaflets only 3 to 5 mm. long; flowers yellow; pods straight or sickle shaped. Locality: Not indicated.

M. falcata aurea Schur (*56*, p. 171).
Flowers golden yellow; pods with short, soft hairs; leaflets obovate-obcordate, toothed at the apex; stems ascending or procumbent. Locality: Austria.

M. falcata pauciflora Lindm. (*36*).
Racemes more open than those of ordinary *M. falcata;* peduncles few (1–4) flowered; flowers small; leaflets very narrow; pods falcate. Locality: Near Odessa, Russia.

M. falcata aureiflora Rouy and Foucaud (*51*, p. 11).
Pods pubescent; flowers golden, almost orange. Locality: Not specified.

M. falcata pubescens Rouy and Foucaud (*51*, p. 11).
Pods pubescent, sometimes almost glabrous; flowers yellow. Locality: France.

Botanical names that have been applied to what are apparently hybrids of Medicago falcata and M. sativa.

M. varia Martyn (*43*, p. 87).
Flowers variegated, showing yellow, green, white, blue, purple, and black; stipules narrower than those of *Medicago sativa.* Locality: Not indicated.

M. media Persoon (*48*).
Peduncles slightly corymbose; flowers pale blue, finally becoming golden yellow; leaflets linear-cuneate, dentate at the apex; pilose below. Locality: Not indicated.

M. falcata versicolor Wallr. (*65*).
Flowers pale blue, finally becoming yellow. Locality: Trotha and Bittendorf, Germany.

M. sativa versicolor Ser. Mss. (*57*, p. 173).
Flowers yellow and blue; equals *M. falcata versicolor* of Wallr., Sched. Crit. Locality: Not specified.

M. falcata hybrida Gaudin (*22*, p. 611).
Flowers pale blue, finally becoming green and yellow. Locality: Nyon, Switzerland. (Gaudin, Flora Helvetica, 1829, v. 4, p. 611.)

M. sativa hybrida Gaudin (*22*, p. 612).
Flowers yellow. Locality: Nyon, Switzerland.

M. falcata tumida Ser. (*57*, p. 172).
Flowers swollen; stamens coalescing to the swollen, slightly fleshy, abortive carpel. Locality: About Geneva. This description would seem to indicate that these flowers are abnormal, in which case the plant is probably a hybrid, as hybrid plants having flowers of similar character have been observed in a number of instances.

M. sylvestris Fries (*21*, p. 92).
Peduncles racemed; banner of corolla oblong, with dark-green striations; pods circular or semicircular. Locality: Skanes, Gothland, and Oland, Sweden. This name is intended by the author to cover all forms of *Medicago falcata* × *sativa.*

M. sativa decolorans Fries (*21*, p. 91).

Stems somewhat decumbent; leaflets often narrower than in ordinary *Medicago sativa;* petals violet, becoming a dirty yellow or finally the color of iron stain. Locality: Southern Sweden.

M. pauciflora Ledeb. (*35*).

Pilose; racemes few (2–4 flowered); pods smooth, spirally coiled; pedicels less than half the length of the calyx, erect after flowering; leaflets cuneate, denticulate at the apex; flowers yellow. Locality: Barku Province, Russia. The author places this plant in a group including plants of white, yellow, blue, and violet flowers.

M. sativa versicolor Koch (*29*, ed. 2).

Flowers bright yellow, changing to green, and later into pale violet. Locality: Not specified.

M. sativa albiflora Babey (*3*).

Flowers pure white. Locality: Environs of Montbeliard, France. Rouy and Foucaud describe this variety as having pubescent pods and whitish flowers.

M. falcata ambigua Trautv. (*61*).

Flowers violet; pods falcate, semicircular or circular. Locality: On the shores of Lake Alkaul, Siberia.

M. sativa atriflora Alefeld (*1*, p. 76).

Like *Medicago falcata* in character of growth and pods, but the flowers on opening are blackish blue. Locality: Not indicated.

M. sativa kochiana Alefeld (*1*, p. 76).

Like *Medicago falcata*, but the flowers are at first yellow, then green, and at last violet. Locality: Not indicated. According to the author, this equals *M. falcata bicolor* of Koch and *M. falcata hybrida* of Gaudin.

M. sativa intermedia Alefeld (*1*, p. 76).

Like *M. sativa kochiana*, but with larger stems, larger and more toothed stipules, and larger flowers. Locality: Not indicated. Alefeld gives this as equal to *M. intermedia* Schultes, *M. procumbens* Besser, and *M. falcata major* of Koch, but from the description it is quite apparent that the plants are very different.

M. sativa rotundifolia Alefeld (*1*, p. 75).

Stems erect; the lower leaflets circular, 5 lines long by 4½ lines broad, the upper ones slightly oblong, 5 lines long and 3 lines broad; bloom bluish yellow; stipules with hairlike serrations, whereas those of the other varieties are short but sharp toothed. Locality: Ladak in Tibet

M. sativa tibetana Alefeld (*1*, p. 75).

Stems ascending, slender; leaflets 8 lines long and 3 lines broad; flowers yellowish blue; pods with 1 to 2½ coils. Locality: Himalayas.

M. sativa pallida Alefeld (*1*, p. 76).

Stems prostrate like *M. falcata;* leaflets 6 lines long by 3 lines broad; bloom light yellow, somewhat larger than ordinary *M. falcata;* pods with 1 to 1½ coils, with an open center 1½ lines wide. Locality: Not indicated.

M. sativa rosea Alefeld (1, p. 75).

Stems erect and similar to *M. vulgaris;* leaflets 8 lines long, 4 lines broad, rather large; flowers bright rose color. Described from a dry specimen. Locality: Not indicated.

M. subfalcata Schur (*55*).

Leaflets obovate-linear; stipules very long acuminate; flowers capitate, variegated, pale yellow at first, changing to green, and finally becoming a dirty violet; pods smooth, forming one coil. Locality: Vicinity of Kronstadt, Hungary.

M. falcata sativa Schur (*55*).

This is given as equal to *Medicago subfalcata* of Schur.

M. lilacea Hy (*27*, p. 432).

Stems prostrate; branches elongated; flowers violet; pods falcate or forming a complete circle. Locality: River Loire, France.

M. spuria Hy (*27*, p. 431).

Stems robust, decumbent; flowers variegated, yellow and violet, deciduous after flowering; the few pods that are formed usually having two coils. Locality: River Loire, near Ponts-de Ce, France. The author states that this is a hybrid of *M. cyclocarpa* and *M. sativa.*

M. cyclocarpa Hy (*27*, p. 431).

Stems prostrate; flowers golden yellow or finally variegated with blue or violet; pods coiled, forming about one spiral. Locality: River Loire, between Laumur and Nantes, France.

M. varia pseudosativa Rouy and Foucaud (*51*, p. 14).

Pods large, glabrescent. Locality: Alpes-Maritimes, France. According to the authors, this is a hybrid of *M. sativa* and *M. falcata*, resembling the female parent and equaling *M. spuria* of Hy.

M. varia pseudofalcata Rouy and Foucaud (*51*, p. 15).

Pods large, glabrescent, with one coil. Locality: Alpes-Maritimes, France.

M. silvestris erectiuscula Rouy and Foucaud (*51*, p. 12).

Stems ascending; corolla yellow, not variegated; pods generally semicircular, glabrescent, or glabrous. Locality: Not specified.

Botanical names that have been applied to species and varieties whose origin and relationship to M. falcata are not clear.

M. glomerata Balbis (*5*).

Pods coiled, hairy; stems erect; leaflets and flowers very much like those of the ordinary *Medicago falcata;* pods glomerate, villous; corolla yellow. Locality: Nice, France.

M. falcata annularis Ser. (*57*, p. 172).

Leaflets narrower and smaller than in ordinary *Medicago falcata;* pods very much arched, almost spiral. Locality: Not indicated.

M. procumbens viscosa Reich. (*49*).

Pods falcate, glandular viscous; flowers bright yellow; seeds 2 to 6. Locality: Saxony, near Dresden.

M. annularis Bess.

This plant is usually referred to as equaling *M. falcata annularis* of Seringe. Besser's description was not available, and it is doubtful whether it was ever published. Koch (*30*) states that he has seen a specimen from Besser in Schultes's collection. Other authors refer to a description of *M. annularis* in Besser's Prim. Fl. Gal. (*9*), but this is evidently an error, as no reference is made to such a plant in that work.

M. falcata glandulosa Koch (*30*).

Pods with scattered, articulated hairs, which are provided with a gland at the end. Locality: Not specified.

M. falcata viscosa Urban (*62*, p. 57).

Pods glandular haired, straight or sickle shaped; flowers yellow. Locality: Not indicated.

M. glandulosa procumbens Schur (*56*, p. 172).

Flowers golden yellow, in loose racemes; pods more or less falcate or almost straight, with inflated glandular hairs; stems prostrate. Locality: Spielberg, Austria.

M. falcata laxiflora subscandens Schur (*56*, p. 172).

Stems weak, climbing among bushes, branching above; leaflets obovate-lanceolate, slightly hairy, toothed at the apex; stipules long, linear-lanceolate, as long as the leafstalk; flowers pale yellow, in loose capitate clusters; pods variously formed, more or less sickle shaped, inflated, glandular haired. Equals *Medicago laxiflora* Schur. Locality: Vicinity of Brunn, Austria.

M. falcata albida calciola Schur (*56*, p. 172).

Flowers white or yellowish white; pods almost smooth or somewhat glandular haired; stems upright; leaflets long to cuneate, slightly grayish green. Locality: Vicinity of Vienna and Brunn, Austria.

M. varia pseudoglomerata Rouy and Foucaud (*51*, p. 15).

Pods somewhat smaller than in ordinary *M. sativa*, glandular pubescent, with 1 to 2 coils. Locality: Alpes-Maritimes.

M. silvestris glandulosa Rouy and Foucaud (*51*, p. 13).

Pods more or less glandular pubescent. Locality: Not specified.

AGRICULTURAL HISTORY.

As far back as mention of *Medicago falcata* can be traced in the history of agriculture it has almost invariably been referred to directly or indirectly as a noncultivated species. Incidentally it may be inferred from certain references by early writers that the plant was utilized in a very limited way for forage in some localities in Europe, but no hint is given that it was cultivated there for that or any other purpose. No attempt has been made to search the literature for information regarding its early utilization in Asia.

The species was at least sufficiently well known to be mentioned in European literature more than three centuries ago, but up to the time of Linnæus (1750–1790) no botanists or agriculturists apparently had ever recommended its domestication. About 1783 Le Blanc (*32*) became interested in the plant, which he termed "Yellow Medick," on account of its ability to produce a good growth on poor soil. He conceived the idea of its domestication, but in the course of his investigations his attention was attracted to a hybrid of *Medicago sativa* and *Medicago falcata*, to which he gave the name "Variegated Medick." In his opinion, this plant was superior to either the common lucern or the yellow medick, and therefore he discontinued his efforts to domesticate the latter.

The literature of the past century contains many references to the cultivation of *Medicago falcata*, but outside of limited localities in India, China, and southern Russia, where it is reported to be cultivated to some extent, it is not grown under cultivation except for experimental purposes. It is a significant fact that regardless of the relationship of *Medicago falcata* to common alfalfa, the early recognition of its value, and the numerous attempts to domesticate it, the plant is still an uncultivated species. However, it must be said that it is probably utilized at the present time more than ever before in Europe and Asia, but wholly as a wild plant on the ranges and in pastures. According to Hansen (*26*, p. 12), it is attracting attention as a range plant in European Russia. Meyer is authority for the statement that the Kalmucks and Sarts in Chinese Turkestan gather it, together with other wild plants, as hay for horses and cattle. Nilsson indicates that it is utilized quite abundantly in Sweden as a wild pasture plant on dry, sandy land. It is reasonable to conclude, therefore, that its value has long been recognized in the agriculture of Europe and Asia. Farther on in this paper some of the reasons for its present agricultural status will be discussed.

COMMON NAMES.

While various common names have been applied to *Medicago falcata*, unfortunately there is none that is without somewhat serious objections. The most satisfactory name that suggests itself and the one that is most commonly used in this country is "yellow-flowered alfalfa." The chief objection to this name lies in the fact that it is not distinctive, there being other fairly distinct species of Medicago belonging to the alfalfa group that have yellow flowers. However, *Medicago falcata* is the most promising member of the yellow-flowered group from a forage standpoint, and it is quite probable that the common name "yellow-flowered alfalfa" will be generally adopted for it. The name "sickle-podded alfalfa" has been occasionally used, but it is cumbersome and harsh sounding. "Siberian alfalfa" meets with objections because the species is by no means confined to Siberia in its natural range. Meyer[1] writes that—

In the southern and central Provinces of Russia and more especially along the Volga River, this wild lucern is called Burgoon. In western Siberia a number of names are in use among the farmers, like Sholty lucern, Sholty klever, Sholty weeseel, and Deekii lucern. These mean, respectively, yellow alfalfa, yellow clover, yellow vetch, and wild alfalfa. The second name, however, applies also to various species of Melilotus, while the third one is given to *Lathyrus pratensis*. The German settlers in the Caucasus in southern Russia and in western Siberia call this wild alfalfa invariably "steinklee," meaning stone clover, or if one gives the word stein a wider meaning, wild clover. In Chinese Turkestan the Turki people call this plant "Tagh-beda," and it seems very likely that the Germans have simply translated this name, since these hardy and industrious settlers have always come much in contact with Tartars and Kirghiz, who all speak Turki dialects. The Dsungans, in Chinese Turkestan, who are Chinese who have become Mohammedans, give *Medicago falcata* the name of "San musu," which means mountain alfalfa or wild alfalfa. The name "musu" is, however, applied to several trifoliate plants in the same way the average person uses the word clover for many widely dis-

[1] In an unpublished report on file in the United States Department of Agriculture.

tinct plants. In the regions around Semipalatinsk on the Irkutsk River in southwestern Siberia where this *Medicago falcata* is especially abundant, the Kirghiz and Russian settlers alike call it "sholteek" and it is this name that the writer proposes to give to the plant. This name "sholteek" is probably a Kirghiz corruption of two Russian words and means something yellowish. Now, however, in the vicinity of Semipalatinsk, this word is being applied apparently exclusively to *Medicago falcata*.

Meyer offers three reasons why the name "sholteek" should be used in preference to other names: (1) That it consists of a single word only; (2) that it is easy to pronounce, easy to remember, and has a pleasing sound; (3) that it is already in use over a large area in Asia, where *Medicago falcata* grows in its greatest abundance. While the name "sholteek" is a somewhat pleasing one and not very difficult to pronounce, it is very doubtful whether any name that does not include the name alfalfa will ever be generally adopted in this country. The names "Orenburg alfalfa" and "Semipalatinsk alfalfa" have been applied to mixed lots of seed introduced from Provinces in Russia and Siberia having these names. The following is a list of some other common names that have been applied to the species, none of which appears to be acceptable (*53*):

Svensk Lucern, Fodorsmare, Gul Lucern, Kosmor, Linne's hofro, Ljungpinnar, Rast, Refgras, Refvagras, Svensk Smare, Deutsche Luzerne, Grosser Steinklee, Schwedisches Heu, Schwedischer Heusame, Schwedische Luzerne, Sickelklee, Spargelklee, Wildes heiliges Heu, Butterjags, Horned Clover, Sickle-podded Medick, Yellow Lucern, Luzerne de Suede, Luzerne faucille, Luzerne Jaune, and Luzerne sauvage.

AGRONOMIC CHARACTERISTICS.

From an agronomic standpoint *Medicago falcata* does not resemble *Medicago sativa* as closely as its botanical relationship would indicate. Habit of growth as regards suitability for hay or pasturage, quantity of growth as indicated by the production of profitable yields under various conditions of soil and climate, and quality of growth or herbage as interpreted in terms of palatability and feeding value are agronomic characteristics that in the main bear little relationship to diagnostic botanical characters. However, no sharp line exists between these two sets of characters, as may be readily seen, for example, in the case of the production of seed. The quantity of seed produced and its retention by the plant are characteristics of considerable botanical as well as agronomic significance.

It is in the agronomic characteristics alone that the farmer is interested, and to a very large degree the plant breeder likewise, since production is the practical end which both must always keep in view. A careful study of the characteristics of the plant which relate directly to its utilization as a forage crop, then, is of the utmost importance. Since most of the agronomic data presented herewith were secured, a number of promising forms have been obtained from India. The data and conclusion, therefore, do not necessarily apply to these late introductions. Their behavior strongly suggests the advisability of deferring judgment on them until they have been more thoroughly tested.

GENERAL HABITS OF GROWTH.

There is a wide range of variation of growth in plants of *Medicago falcata.* Practically every degree of erectness is represented, from prostrate to upright. However, from a forage standpoint the species may be divided into two general groups—the procumbent, prostrate, or spreading group, which, theoretically at least, has some advantages over the upright forms for pasturage, and the ascending or suberect group, which is suitable for hay production. Oliver (*47*) has discussed the pasture forms in some detail. A large majority of the forms fall either in the so-called pasture group or are not sufficiently erect to be included in the hay group. The apparently prevalent opinion, however, that there are no upright forms is erroneous, since there are some quite as erect as any that can be found in *Medicago sativa.* The degree of erectness, it is true, is influenced to some extent by cultural methods. The habit of the plants is dependent to a considerable degree upon whether they are grown in hills, widely spaced rows, or in broadcast stands. In hills and in rows they are much more procumbent than when grown in broadcast stands. However, thickness of planting does not overcome the decumbent habit of the plants in groups 1 and 2 sufficiently to permit harvesting by machinery without loss. Observations made at Brookings, S. Dak., on two tenth-acre broadcast plats seeded in 1909 indicate an appreciable improvement in the degree of erectness of the plants after the stand becomes thickened by the enlarging of the crowns, which was especially noticeable after the second or third year of growth.

The forms suitable for hay, so far as the matter of harvesting is concerned, are confined almost exclusively to groups 3 and 4. These forms are found abundantly in S. P. I. Nos. 20718, 20719, 24455, 26927, 28070, 28071, 30433, and 32412. (See figs. 12, 13, 14, and 15.) The extremely low, spreading pasture forms are found in groups 1 and 2, and especially in S. P. I. Nos. 20717, 20725, and 24454, where they predominate. (See figs. 7, 8, and 9.)

CHARACTERISTICS OF THE VEGETATIVE GROWTH.

The general appearance of the vegetative growth of the upright forms of *Medicago falcata* is not materially different from that of *Medicago sativa*, except that it is somewhat more silver gray in color. The mass height in broadcast stands is commonly less than that of

Medicago sativa, although in a few of the erect forms there is comparatively little difference in this respect. From a similar stand of the same height of mass growth *Medicago falcata* will produce a heavier yield than *Medicago sativa*, partly because of the thicker growth of stems and partly because of the texture of the herbage. Estimates of yields based upon appearance therefore commonly err in favor of *Medicago sativa*. Conditions of soil and stand being equal, individual cuttings of the best upright forms of *Medicago falcata* frequently outyield those of varieties of *Medicago sativa*.

A characteristic of considerable importance in any hay crop is the proportion, by weight, of leaf to stem. The plants of *Medicago falcata* show great variation in this respect, making the character of little value in any system of classification. However, in the very low forms the proportion is greater than in the more erect ones. A critical study of 27 S. P. I. introductions indicates that the leaves compose from 34.5 per cent to 67.5 per cent of the total dry weight of the herbage. The highest percentage of leaves was found in group 1 in plants of S. P. I. Nos. 20717 and 20725. McKee (*42*) presents data on the percentage of leaves by weight for three varieties of *Medicago sativa*, as follows:

Peruvian	52. 5 per cent.
Arabian	56. 4 per cent.
Common (Utah grown)	49. 8 per cent.

According to the investigations of the Utah Agricultural Experiment Station (*67*) the percentage of leaves by weight in common alfalfa ranges from 22.7 to 38.4, depending upon the stage of maturity. It is safe to assume that the erect forms of *Medicago falcata* are not essentially different from the common varieties of *Medicago sativa* with respect to the above character. The leaves of the former, however, are retained after curing to a greater degree than those of the latter, which is a very important factor.

STEM CHARACTERISTICS.

The size and number of stems of the plant vary greatly with its habit of growth. (Fig. 17.) In the very procumbent or prostrate plants the stems usually are finer and more abundant than in the more erect ones. An actual count made on plants 4 years old indicates the number of stems to range from 292 in S. P. I. No. 20718, a large ascending form, to 1,682 in S. P. I. No. 20717, a broad-crowned form. Plants of Turkestan alfalfa of the same age and grown under similar conditions had approximately 225 stems per plant. In this agronomic character also *Medicago falcata* compares very favorably with *Medicago sativa*.

PERIODS OF GROWTH.

Observations made at Brookings in 1912, 1913, and 1914 indicate that *Medicago falcata* has a tendency to commence growth earlier in the spring than *Medicago sativa* or *Medicago sativa* × *falcata* hybrids. This characteristic is apparently influenced by climatic and soil conditions. If, as frequently happens in early spring, a short period favorable for growth is followed by continued cool or cold weather, the difference between the quantity of growth of *Medicago falcata* and *Medicago sativa* when the growing season really begins is very noticeable. This probably is due to the fact that while both may

FIG. 17.—Loose bunches of stems of various forms of *Medicago falcata,* showing general types of growth.

start during the favorable period, the former is able to outgrow the latter during the unfavorable period following.

At Highmore, S. Dak., in the spring of 1912, *Medicago falcata* continued growth throughout an extended period of very cold weather, while *Medicago sativa* made very little growth. The same phenomenon was observed at Brookings, but the difference between the two was not so pronounced. In the spring of 1914 the difference in the earliness of growth was less noticeable than in the other seasons mentioned. The soil was extremely dry until well into April that year, after which the conditions of warmth and moisture were unusually favorable, resulting in good growth of all varieties. It seems reasonable that the lack of difference between the spring growth of *Medi-*

cago falcata and *Medicago sativa* in this instance may have been due to these conditions, particularly to the dryness of the soil.

The various forms of *Medicago falcata* exhibit slight differences in the earliness of spring growth. It seems to be true that young plants of all alfalfas start growth earlier than old plants. Therefore, only plants of the same age should be compared in making observations on this point.

In his discussion of Peruvian alfalfa, which he describes as *Medicago sativa* variety *polia*, Brand (*12*) calls attention to the ability of this strain to continue growth during the late fall and winter when other varieties of *Medicago sativa* become dormant on account of the low temperature. The term "zero point" is applied by him to the minimum temperature at which growth can be made. He consequently classes Peruvian alfalfa as a variety which has a low zero point and common alfalfa as a variety with a comparatively high zero point. Brand's observations were made in southern Arizona, and had *Medicago falcata* been studied in comparison with the varieties of *Medicago sativa* it doubtless would have been considered as having the highest zero point of all, since it discontinues growth in the Southwest earlier than any of the other varieties of alfalfa.

A study of the various alfalfas at different latitudes with regard to their phenological characteristics reveals some rather interesting and important points. The most important of all, perhaps, is the effect of severely low temperatures on their so-called zero points of growth. This can be explained best by citing the behavior of the distinct forms in different parts of the country. In California and the far Southwest, McKee finds it readily possible to distinguish Peruvian alfalfa, common alfalfa, *Medicago sativa* × *falcata* hybrids (the general group of variegated alfalfas), and *Medicago falcata* by their growth in late fall and early spring, without regard to their morphological characters. They discontinue growth in the fall and resume it in the spring in the order in which they are named above. The same order obtains in general at the Arlington Farm, Va., with some seasonal variation, but at Brookings and Highmore there is a tendency toward the reversal of this order. The latitude of Washington, D. C., appears to be about the dividing line, if high altitudes are excepted.

SPRING GROWTH.

Westgate (*66*) in discussing *Medicago falcata* × *sativa* hybrids says, "in earliness of starting in spring as well as in earliness in blooming, the variegated alfalfas appear to exceed the ordinary kinds." He qualifies this statement somewhat by saying "In the southern one-half of the United States the variegated alfalfas are normally later in starting than the ordinary variety." This indicates possibilities worth considering in the development of new agronomic strains of alfalfa through the hybridization of *Medicago sativa* and *Medicago falcata.* It seems quite probable that severely low temperatures materially influence the ability of varieties to commence growth in the spring. In the colder and drier portions of the Great Plains area a variety of alfalfa making a growth in the early spring is more certain of producing a good crop of hay than those that are slow in starting, as it is able to take advantage of the winter moisture. Since one good cutting is sometimes all that can be obtained, the ability of a variety to produce early spring growth is of considerable importance. *Medicago falcata* not only possesses this characteristic, but is able to transmit it in some degree to the progeny resulting from its hybridization with *Medicago sativa.*

In May, 1915, the effects of the five severe frosts and freezes which occurred during that month were observed on the nursery rows at Redfield, S. Dak. The rows of *Medicago falcata* showed decidedly less damage than the adjoining rows of *Medicago sativa.* It is true that the plants of the former, being of lower growth than those of the latter, may have received some protection from the earth. With the exception of the introductions from India, S. P. I. Nos. 26927, 29139, and 30433, the *Medicago falcata* plants showed almost no frost effect, while those of *Medicago sativa* were badly wilted. The effect of the frost was apparently the same on the Grimm, Canadian variegated. Baltic, Turkestan, and local Dakota strains.

RECOVERY AFTER CUTTING.

A characteristic wherein *Medicago falcata* differs materially from *Medicago sativa* is in rate of growth after cutting. The ability to produce several crops of hay in a season under favorable conditions has been largely responsible for the popularity which the latter has had for centuries. Unfortunately, the former does not possess this ability to any considerable degree; in fact, only under very favorable conditions can more than one good cutting be procured from it.

Table II indicates the comparative rate of recovery of *Medicago falcata* and *Medicago sativa* after cutting at Brookings.

TABLE II.—*Comparative rate of recovery of Medicago falcata and Medicago sativa after cutting, at Brookings, S. Dak., in 1913.*

Plants cut June 19.	Height of growth—	
	July 8.	July 22.
	Inches.	*Inches.*
Medicago falcata, seven introductions	4 to 9	8 to 13
Medicago sativa, two strains	16	19 to 20

The above data are verified by those obtained at Highmore, where plants grown in hills 44 by 44 inches were cut and the recovery noted. A brief summary of the results is presented in Table III.

TABLE III.—*Rate of recovery of Medicago falcata after cutting, at Highmore, S. Dak., in 1913.*

S. P. I. No.[1]	Average measurement of plants.		Date harvested.	Average height on July 17.	S. P. I. No.[1]	Average measurement of plants.		Date harvested.	Average height on July 17.
	Height.	Spread.				Height.	Spread.		
	Inches.	*Inches.*		*Inches.*		*Inches.*	*Inches.*		*Inches.*
20717	12⅛	35⅝	June 27	3½	20725	12½	36½	June 27	4⅛
20718	21	45½	June 23	7¼	24452	17¼	43¼	June 24	6¾
20721	18¾	39⅛	June 14	7¾	28070	23¼	41½	June 24	7⅜
20722	19	35¾	June 17	7	28071	20⅝	44	June 23	4⅜

[1] Observations were made on eight plants of each number.

As will be noted, there is some difference in the rate of recovery of the various introductions, but this ordinarily is small and can scarcely be considered as a fixed characteristic of any of the forms. Observations made on plats where strains of *Medicago falcata* were grown in broadcast stands indicate that the growth after cutting is less than when grown in rows and hills. The specific data herein recorded are supported by general data published by the Dickinson (N. Dak.) substation (*64*) and in reports of the Canadian Experimental Farms (*41*).

LATE AUTUMN GROWTH.

The difference in the comparative rate of growth of *Medicago falcata* and *Medicago sativa* in the autumn is influenced to a great extent by temperature. In October, 1913, notes were taken at Brookings on the effect on the various alfalfas of a hard freeze that occurred September 22, when the temperature reached 17° F. In general, the plants of *Medicago falcata* were little affected, and nearly all that were recorded then as being injured were later found to be hybrids of *Medicago falcata* and *Medicago sativa*. The various strains of *Medicago sativa* were very noticeably injured, while the hybrids were also injured, but to a somewhat less degree.

In a season of relatively high fall temperatures and favorable moisture conditions plants of *Medicago sativa* will produce more late fall growth than those of *Medicago falcata*. This is quite in accordance with the previous discussion under "Spring growth."

HARDINESS.

The characteristic of hardiness in plants is commonly defined as ability to endure cold. It has recently, however, come to have a broader meaning; namely, the ability to survive winter conditions.

Among the factors influencing winterkilling may be mentioned low temperature, excessive variation in temperature, protection as afforded by snow and drifted soil, thickness of stand of plants, precipitation, vigor of plants upon entering the winter, and condition of soil with respect to moisture, surface drainage, and existence of ice sheets.

Medicago falcata is generally regarded as a hardy species, and it was for this reason that efforts were made to introduce as many of its forms as possible from regions where it is found growing naturally. While it scarcely could be expected that forms of the species from the Mediterranean region would be as hardy as those from the vicinity of Yakutsk, 62° north latitude, where the temperature reaches —84° F., it is probable that most of the forms can be placed in the class of comparatively hardy alfalfas, regardless of the geographical location in which they were developed. Just why some varieties of alfalfa are more susceptible than others to winter conditions is not clearly understood. It is now commonly believed, however, that an important factor in the hardiness of any variety is the degree of protection which the plant provides its dormant or resting buds. For example, varieties in which the crowns are produced well above the surface of the ground are uniformly tender, while those in which the crowns are near or beneath the surface are mostly hardy. The Arabian and Peruvian varieties may be cited as illustrations of the former, while the Grimm and Baltic varieties represent the latter group. The dormant buds of the varieties with high crowns are fully exposed to the unfavorable conditions of winter, while those of the varieties having low crowns are protected by the soil, and to some extent by the dead herbage of the preceding summer. The relation of deeply set crowns to hardiness probably was first called to attention in agricultural literature by Thomas Le Blanc in 1791 (*32*), but it is only within recent years that the significance of this characteristic of the crown has been duly appreciated (*45*, p. 4).

A majority of the forms of *Medicago falcata* produce at least a part of their new growth from underground members, either rhizomes or true lateral roots, a characteristic which affords material protection during periods of severe conditions. It is largely upon this feature, as well as upon its geographical range, that the estimate of its hardiness has been based.

While comparative tests of the hardiness of *Medicago falcata* and strains of *Medicago sativa* grown in rows and hills have been made since 1910, there are still insufficient critical data from which to draw definite conclusions as to the relative hardiness of the former under actual field conditions. Unfortunately, many of the plantings that were made in 1909 were poorly provided with checks and did not include the common commercial strains of *Medicago sativa* to a sufficient extent. Nevertheless, the results from these and other plantings go far toward proving the hardiness of *Medicago falcata.*

In the fall of 1910, counts were made of plants of one variety of *Medicago sativa*, three hybrid strains, and several numbers of *Medicago falcata* at Brookings and Highmore. At the former place the plants were grown in hills 24 by 36 inches, and at the latter in hills 44 by 44 inches. The following spring, counts were made to determine the percentage of plants that survived the winter, with the results shown in Table IV.

TABLE IV.—*Comparative winterkilling of Medicago falcata and Medicago sativa*[1] *grown at Brookings and Highmore, S. Dak., 1910–11.*

Species.	S. P. I. No.	Brookings.			Highmore.		
		Living plants.		Surviving.	Living plants.		Surviving.
		November, 1910.	April, 1911.		November, 1910.	April, 1911.	
				Per cent.			*Per cent.*
Medicago sativa	20711	238	231	97.0	112	15	13.3
Medicago sativa × Medicago falcata	20571	256	252	98.4	119	85	71.4
Do	20714	497	488	98.1	111	18	16.2
Do	20716	298	287	96.6	74	20	27.0
Medicago falcata	20717	265	264	99.6	355	344	96.0
Do	20718	318	305	95.9	148	144	97.3
Do	20719	245	242	98.7	323	323	100
Do	20720	65	65	100			
Do	20721	261	257	98.4	350	297	84.8
Do	20722	250	244	97.6	286	245	85.6
Do	20724	39	39	100			
Do	20725	259	259	100	354	334	94.3
Do	20726	311	311	100			
Do	24452	771	771	100	185	182	98.3
Do	24453	56	56	100			
Do	24454	501	501	100			
Do	24455	322	322	100			
Do	24456	61	61	100			
Average percentage of survival:							
Medicago sativa				97.0			13.3
Medicago falcata × Medicago sativa				97.7			38.2
Medicago falcata				99.2			94.8

[1] The *Medicago sativa* variety used in this test was a selected strain of Turkestan alfalfa. The hybrids were the North Sweden, Cossack, and Cherno varieties.

The minimum temperatures for the winter months at Brookings and Highmore are given in Table V.

TABLE V.—*Minimum temperature (°F.) in each month of the winter of 1910–11, at Brookings and Highmore, S. Dak.*

Locality.	November.	December.	January.	February.
Brookings	5	−16	−32	−9
Highmore	3	−18	−24	−11

The summary of results at Brookings and Highmore indicates the superior hardiness of *Medicago falcata* at these points, while Table V indicates that factors other than low temperature were responsible for winterkilling.

While the number of plants upon which the percentage of survival shown in Table IV was based is too small to make the data really dependable, the appearance of the plantings at Highmore was very convincing. The rows of Turkestan, North Sweden, Cossack, and Cherno were so depleted as to give the entire block an extremely ragged appearance, while the rows of *Medicago falcata* adjoining had so nearly the full quota of plants that the mass effect remained unbroken. (Figs. 18 and 19.)

Widely spaced hill plantings, such as were made at Highmore, in some respects offer very good opportunity for studying winterkilling, since on such plantings the effect of the important factors is greatly exaggerated. In row plantings and even in broadcast stands at Highmore the mortality of the *Medicago sativa* varieties

FIG. 18.—Hill plantings of *Medicago falcata* varieties, *M. sativa,* and *M. sativa*×*falcata,* commercial varieties and selections. Photographed in August, 1910, Highmore, S. Dak.

was slight, while it was almost negligible in the case of the *Medicago falcata* strains. At Brookings the only winterkilling of *Medicago falcata* which could be considered of any consequence occurred during the season of 1912–13. The mortality in this case was doubtless due to the presence of an ice sheet over a portion of the plats. It is well recognized that Brookings and Highmore are not ideal places at which to test the comparative hardiness of alfalfas; nevertheless, at the latter point winterkilling is a serious factor in common alfalfa under field conditions.

Georgeson (*23*) reports *Medicago falcata* to be the hardiest of all the alfalfas tested in Alaska and that it survives the winter without "inconvenience." His tests, which included the Grimm and other variegated strains, were made under conditions much less severe than those normally obtaining in the Dakotas.

In all the trials which have been reported there is still lack of data on the relative hardiness of the various forms of the species. It now seems probable that this fact will be determined only indirectly; that is, by determining the relative hardiness of their hybrids with *Medicago sativa*, since many of them are of themselves not of sufficient agronomic importance to justify the expense of extensive tests of hardiness. Several introductions, however, including two lots from India, which have been tested at the University of Saskatchewan, Saskatoon, Saskatchewan, for three or more years, show no perceptible difference in their ability to survive the winter conditions.

Taking into consideration the geographical range of *Medicago falcata*, the provisions made by its various forms for the protection of the buds during the dormant season, and the results of tests in this country and elsewhere, it is fair to assume that the species may well be considered hardy as compared with the commercial strains of *Medicago sativa*. Through this physiological characteristic the various forms of the species will aid in solving the alfalfa problem in the colder and drier portions of the United States.

Fig. 19.—The hill plantings of alfalfa shown in figure 22. Photographed in May, 1911. The solid plantation in the background is of *Medicago falcata* varieties. The scattering plants in the foreground are *M. sativa* and *M. sativa*×*falcata* strains. The difference in winterkilling between the last two and the first was very marked.

DROUGHT RESISTANCE.

Within recent years the relation existing between drought resistance and cold resistance has become more definitely recognized. The adaptations of the plant which make it resistant to cold are now believed to enable it in a large measure to endure or evade drought. The prevailing opinions regarding the drought resistance of *Medicago falcata* have been based chiefly on the fact that it grows naturally in very dry situations and possesses certain characteristics which are ordinarily considered as drought-resisting adaptations. No critical data are available from plants grown under cultivation, but the general results leave little doubt that most of the forms of *Medicago falcata* are relatively drought resistant, and certain forms at least will endure drought conditions too severe for *Medicago sativa*.

The factors that are potent in enabling it to resist drought are its extensive root development, its ability to produce rhizomes well beneath the surface of the soil and in certain cases to produce true proliferating lateral roots, and its ability to suspend activity and to lessen transpiration by reducing its leaf surface. During periods of severe drought it makes very little growth above ground, but apparently devotes some energy to the production of rhizomes, from which new growth develops either with the resumption of favorable conditions the same season or in the following spring. This adaptation is of considerable benefit in carrying plants through the critical periods of summer.

The following heretofore unpublished data on the water requirement of *Medicago falcata*, by which is meant the quantity of water required by the species to produce a given amount of dry matter, as determined by the method of Briggs and Shantz, have been furnished by Mr. A. C. Dillman, of the Office of Alkali and Drought Resistant Plant Investigations.

A summary of the water requirement of *Medicago falcata* as compared with that of *Medicago sativa* (the Grimm variety), as determined at Newell, S. Dak., for four seasons, 1912 to 1915, inclusive, and at Akron, Colo., in 1914, is given in the following table:

TABLE VI.—*Comparative water requirement of Medicago falcata and Medicago sativa at Newell, S. Dak., in 1912 to 1915, inclusive, and at Akron, Colo., in 1914.*

Place, year, and species.	Water requirement based on dry matter.							
	Actual.				Relative.			
	First crop.	Second crop.	Third crop.	Combined crops.	First crop.	Second crop.	Third crop.	Combined crops.
AT NEWELL, S. DAK.								
Season of 1912:[1]								
Medicago falcata	622±15	735±18		663±12	89	95		90
Medicago sativa	699±15	772±18		735±15	100	100		100
Season of 1913:								
Medicago falcata	340± 7	713±11	1,220±52	579±12	73	87	109	79
Medicago sativa	469± 6	817±13	1,115±16	735± 8	100	100	100	100
Season of 1914:[2]								
Medicago falcata	503±38	930±26		687±20	93	116		103
Medicago sativa	539	800		669	100	100		100
Season of 1915:								
Medicago falcata	399± 8	424± 4	1,108±20	541± 9	94	103	176	108
Medicago sativa	424± 9	413± 7	630±18	499± 7	100	100	100	100
Mean at Newell:								
Medicago falcata					87	100	142	95
Medicago sativa					100	100	100	100
AT AKRON, COLO.								
Season of 1914:[1]								
Medicago falcata	652±16	757±13	1,201±75	848±27	107	84	114	95
Medicago sativa	610± 3	907±14	1,055±12	890± 6	100	100	100	100
Mean at both Newell and Akron:								
Medicago falcata					91	97	133	95
Medicago sativa					100	100	100	100

[1] The data at Newell, S. Dak., in 1912, and at Akron, Colo., in 1914, were procured from seedling plants, while those obtained at Newell in 1913 to 1915, inclusive, were from plants a year or more old.
[2] At Newell, S. Dak., in 1914 there were five pots of *Medicago falcata*, but only one pot of *Medicago sativa*.

The actual water requirement of the first, second, third, and combined crops for each year is given in the second to fourth columns of the table, and the relative water requirement of each crop, with *Medicago sativa* taken as 100, is given in the last four columns of Table VI. Considering the water requirement of the combined crops, it will be noted that *Medicago falcata* has a slightly lower requirement than *Medicago sativa.* The water requirement of *Medicago falcata*, based on data obtained from 29 separate pots which are summarized in the table, is 663±15, and the water requirement of *Medicago sativa*, as determined from 25 separate pots, is 713±18, or a difference of 50±23 in favor of *Medicago falcata.* This difference, in view of the large probable error, which was in part due to variation in season and location, is not significant. It would appear from the above data that *Medicago falcata* is relatively efficient in its use of water during the early part of the season, but inefficient during the late summer.

There is little doubt that the drought resistance of *Medicago falcata* is quite as high as that of *Medicago sativa*, but it is unlikely that the former can be grown profitably where the latter succumbs. There is a vast agronomic difference between being able to maintain an existence under extremely dry conditions and being able to produce sufficient growth to be profitably utilized for hay or pasture. There is certainly no definite evidence that *Medicago falcata* will be profitable where the better adapted strains of *Medicago sativa* fail.

SEED PRODUCTION.

The seeding habits of *Medicago falcata* are such as to give serious concern in connection with its utilization as a cultivated forage crop. Not only is the quantity of seed produced comparatively small, but a large percentage shatters before it can be harvested by ordinary methods. Even in harvesting by hand the loss of seed through shattering is great. There are no data available on yields of seed under field conditions, but there are numerous data on yields from individual plants, from which estimates can be made of the yields which might reasonably be expected under field conditions.

At Brookings, yields from a large number of plants were recorded from 1910 to 1913, inclusive. The plants were grown in hills 24 by 36 inches, thus providing what are generally considered very satisfactory conditions for seed production. Special care was exercised in harvesting the seed to reduce the shattering to a minimum. Therefore the yield was appreciably greater than if the plants had been harvested by ordinary field methods, and was high also for a fair comparison with *Medicago sativa.*

TABLE VII.—*Alfalfa plants transplanted in 1909 to hills 24 by 36 inches at Brookings, S. Dak., showing yields of seed, 1910 to 1913, inclusive.*

Species.	S. P. I. No.	No. of plants.	Yield of seed per plant (grams).				
			1910	1911	1912	1913	Average.
Medicago sativa	20711	145	2.80	3.70	0.924	1.333	2.188
Medicago sativa × Medicago falcata	20571	248	2.92	4.61	1.506	.709	2.436
Do	20714	418	2.72	3.90	1.108	.641	2.092
Do	20716	263	3.46	6.80	2.231	1.353	3.461
Medicago falcata	20717	261	1.44		.421	.038	.633
Do	20718	243	.35	.084	.352	.181	.241
Do	20719	234	.37	.025	.074	.085	.138
Do	20720	62			.209	.258	.233
Do	20721	159	.205	.126	.477	.157	.241
Do	20722	213	.216	.082	.375	.122	.198
Do	20725	225	1.69		.613	.044	.782
Do	20726	238	1.44	1.22	.586	.247	.873
Do	24452	708	1.28	.135	.405	.210	.507
Do	24454	434	.19		.180	.073	.147
Do	24455	156	.53	.366	.213	.115	.306
Do	24456	59			.205	.169	.187
Do	28070	177	.142	.073	.100		.105
Do	28071	122	.47	.29	.176	.147	.270
Average yield of seed:							
Medicago sativa							2.188
Medicago sativa × Medicago falcata							2.663
Medicago falcata							.347

A summary of Table VII shows clearly the relatively low yield of seed from *Medicago falcata.* Allowing amply for the variation in its different forms, there is none that approaches the ordinary forms of *Medicago sativa* in seed production. In view of the extreme uncertainty of the seed crop in the case of common alfalfa, there is reason to assume that the utilization of *Medicago falcata* as a cultivated crop will be seriously handicapped by the precarious nature of its seed production.

In addition to scanty seed setting and the material loss from shattering, an appreciable percentage of the seed is "hard" and of doubtful value for sowing. As previously indicated in this paper, 50 per cent of hard seed is commonly found in the various strains of *Medicago falcata.* While the germination of a portion of this seed can be hastened by treatment, no thoroughly practicable method has yet been developed either for scratching the seed coat or rendering it more permeable to water by the use of chemicals. There is also an appreciable percentage of shriveled and nonviable seed, so that the proportion of readily germinable seed rarely exceeds 40 per cent. Preliminary tests indicate that the viability increases with age to a limited degree, aging apparently reducing the percentage of hard seed.

The comparatively small size of the seed offsets to some extent for agronomic purposes the effect of the high percentage of hard seed. There are approximately 325,000 to 490,000 seeds of *Medicago fal-*

cata per pound and only 200,000 to 250,000 seeds of *Medicago sativa* per pound. However, this difference in the size of the seed does not apparently affect the quantity necessary to produce a stand of plants in the field to the extent that theoretically might be expected.

YIELDS OF HAY.

A correct estimate of the yield of hay of *Medicago falcata* compared with that of *Medicago sativa* is difficult to make. The actual production is more nearly the same for the two species than are the yields obtained by ordinary methods of harvesting, owing to the failure of the mowing machine to cut all the procumbent or decumbent stems of the latter. Yields of hay have been obtained from a large number of individual plants cut with a hand sickle, but only a few data are available on yields from field plats harvested by machinery. The yields presented in Table VIII were obtained from tenth-acre broadcast plats at Brookings.

Table VIII.—*Yields of alfalfa obtained from tenth-acre broadcast plats, Brookings, S. Dak., 1910 to 1913, inclusive.*

Species.[1]	Calculated yield per acre (in pounds) based on actual yields from tenth-acre plats.															
	1910			1911			1912				1913				Average yield, all years.
	Cuttings.		Total.	Cuttings.		Total.	Cuttings.			Total.	Cuttings.			Total.	
	1	2		1	2		1	2	3		1	2	3		
Medicago sativa:															
Grimm	1,560	850	2,410	1,070	(2)	1,070	4,280	2,140	2,600	9,020	1,120	1,860	380	3,360	3,965
Do	1,500	520	2,020	860	(2)	860	4,120	2,780	2,210	9,910	1,450	1,660	280	3,390	3,845
Common	1,050	560	1,610	1,010	(2)	1,010	4,080	2,960	1,780	8,820	1,400	1,770	610	3,780	3,805
Turkestan	1,310	730	2,040	900	(2)	900	4,050	2,420	1,410	7,880	2,800	1,250	530	4,580	3,850
Medicago falcata:															
S. P. I. 20717[3]	1,650	(2)	1,650	270	(2)	270	2,681	(2)	(2)	2,681	1,710	(2)	(2)	1,710	1,577
S. P. I. 24452[3]	2,780	(2)	2,780	880	(2)	880	4,819	(2)	(2)	4,819	2,720	(2)	(2)	2,720	2,799

[1] All plats sown in 1909 under similar conditions. [2] No second or third crop secured.
[3] Yield in 1910 considerably increased by weeds.

It is clearly shown in Table VIII that the average yield of *Medicago falcata* is appreciably lower than the yields of the varieties of *Medicago sativa.* Only during the unfavorable years of 1910 and 1911 did the former equal or approach the latter in total hay production, and this was due largely to the growth of weeds that developed in the plats. In 1910 a very light second cutting of Grimm, common, and Turkestan alfalfas was obtained, but in 1911 only one cutting was secured.

In years that are favorable for the production of only one crop, the best hay forms of *Medicago falcata* may produce as heavy yields as the varieties of *Medicago sativa*, and in some cases even greater yields. But where the supply of moisture is normally insufficient to produce more than one cutting a season, there is real doubt as to whether the culture of alfalfa is warranted except on a limited scale. It will be noted from Table VIII that in none of the years was more than one cutting of *Medicago falcata* produced, while in 1912 and 1913, years with favorable growing seasons, the three cuttings of *Medicago sativa* gave a total yield far in excess of that obtained even from the best number of *Medicago falcata*. In these years the *Medicago falcata* plats produced some growth after cutting, but not sufficient to be harvested by field machinery. The data in the table are supported by the results obtained by the North Dakota substation at Dickinson, N. Dak. (*64*), and by tests at Lacombe, Alberta, and Indian Head, Saskatchewan (*41*).

Estimates of yield per acre based on yields of hay from widely spaced individual plants harvested by a hand sickle are more favorable to *Medicago falcata* than are the data obtained from fields harvested by machinery. *Medicago falcata* in hills 3 feet or more apart has a tendency to produce larger plants than *Medicago sativa* under such conditions. While its recovery after cutting commonly is slight, it is frequently sufficient to permit harvesting by means of a sickle, which perceptibly increases the total yield of the season.

FEEDING VALUE.

Data procured from the various regions where *Medicago falcata* grows naturally in considerable abundance indicate that it is regarded as of high feeding value. The reports of Nilsson from Sweden; Prof. Williams,[1] of Moscow; Mr. M. S. Bogden, a Russian agronomist, Krassny Koot, Samara Government, Russia; David (*18*) from Mongolia; Galwan[1] from India; and Hansen and Meyer from numerous parts of Asia are on this point at least very favorable, if not enthusiastic.

There appear to be no available records of definite feeding tests in which *Medicago falcata* has been carefully compared with common alfalfa or other standard forage crops. If chemical analyses are accepted as an indication of the feeding value, it is reasonable to assume that this species is at least as nutritious as *Medicago sativa*. Analyses were made of samples of the former grown at Highmore and are given here mainly for comparison with the average of numerous analyses of the latter. (Table IX.)

[1] In a letter on file in the United States Department of Agriculture.

TABLE IX.—*Chemical analyses of Medicago falcata and Medicago sativa.*[1]

Species and S. P. I. No.	Group.	Chemical composition on water-free basis (per cent).				
		Ash.	Ether extract.	Protein.	Crude fiber.	Nitrogen-free extract.
Medicago falcata:						
20717	1	8.90	2.97	21.61	21.51	44.99
20725	1	9.75	2.14	19.62	29.19	39.27
20718	2	7.80	1.63	17.60	33.77	39.17
24452	2	8.13	1.81	16.02	36.98	37.03
20721	3	8.64	1.51	17.65	33.14	39.04
20722	3	10.10	1.54	18.26	30.38	39.70
28070	3	9.35	1.70	19.94	33.81	35.17
28071	3	7.84	2.30	17.21	31.96	40.67
Medicago sativa:						
Average of 21 samples[2]		8.07	2.40	15.61	27.40	46.61

[1] Analyses made in the Miscellaneous Laboratory of the Bureau of Chemistry, Department of Agriculture.
[2] From Farmers' Bulletin 339, p. 28.

The analyses indicate a remarkable uniformity in the chemical composition of the various forms of *Medicago falcata* and a somewhat higher protein content than is found in the average of 21 samples of *Medicago sativa.* The relatively large proportion, by weight, of leaves to stem and the degree to which the leaves are retained on the cured plant doubtless have a bearing on this point.

The fresh leaves of practically all the forms of *Medicago falcata* are rather bitter, and this characteristic may affect to some extent their palatability, and incidentally their feeding value. Observations, however, indicate that animals eat the hay with avidity, and Meyer is of the opinion that the hay is even more palatable than that made from common alfalfa. The percentage of crude fiber in the suberect forms of the species is appreciably higher than in varieties of *Medicago sativa* and doubtless reduces their nutritive value to some extent.

Summing up the evidence briefly, it is reasonable to conclude that *Medicago falcata* is a highly nutritious forage plant and approximately equal to common alfalfa in feeding value.

CULTURAL INVESTIGATIONS.

Strictly speaking, the cultural investigations that have been conducted with *Medicago falcata* have not been extensive, owing partly to an insufficient supply of seed for large plantings and partly to the fact that other lines of investigation have been, and still are, considered of much more importance. Broadcast seeding in rows sufficiently spaced for cultivation and seeding and transplanting in widely spaced hills have been tested and the behavior of the various forms of the species observed under these conditions. In each case comparisons with common alfalfa were made as fully as possible.

BROADCAST SEEDINGS.

A serious difficulty was encountered in obtaining a satisfactory stand in tests where broadcast seeding was employed, owing primarily to the high percentage of hard seed and the slow early growth of the seedlings. Reasonably good stands were obtained, however, at Brookings in May, 1909, as the result of sowing on well-prepared land at the rate of 10 pounds per acre without a nurse crop. One of the plats had a thin stand for the first two years, but as the plants became older the low crowns spread sufficiently to produce a thick stand. (Fig. 20.) Such a condition rarely, if ever, obtains in the case of *Medicago sativa*. A stand of this species, thin at the outset, usually becomes thinner as time elapses. While the individual plants become larger with age, the mortality in common alfalfa is sufficient to seriously deplete the stand.

FIG. 20.—A plat of *Medicago falcata*, Brookings, S. Dak., sown broadcast in the spring at the rate of 10 pounds to the acre.

In broadcast seedings the procumbent forms of *Medicago falcata* are inclined to be more nearly erect than in hills or row plantings, but even where good broadcast stands are obtained, the procumbent tendency is still sufficient to occasion considerable loss in harvesting. (Fig. 21.) In plats where *Bromus inermis* had volunteered, the loss in harvesting was appreciably diminished and a material increase in total yield was obtained. (Fig. 22.)

So far as may be determined from preliminary investigations, it would appear that although more difficulty is experienced in obtaining a satisfactory stand from broadcast seeding, the cultural requirements of *Medicago falcata* are essentially the same as those for *Medicago sativa.*

CULTIVATED ROWS.

There is nothing unusual in the behavior of *Medicago falcata* in cultivated rows. The yields of both hay and seed bear approximately the same relation to the yields of *Medicago sativa* under such conditions as they do in broadcast sowings. The poor germination of the seed and the slowness of growth of the seedlings occasion difficulty in the cultivation of the rows while the plants are young. This can be obviated to some extent by mixing with the seed a small

FIG. 21.—A broadcast plat of *Medicago falcata* after cutting with the mowing machine. Note the failure of the mower to cut many of the decumbent stems.

quantity of some quickly germinating seed that produces large seedlings which disappear before endangering the alfalfa plants. In experimental plantings, refuse radish seed has answered the purpose very well, but such seed is not available for planting on a field scale. A 42-inch row has given very satisfactory results in tests. On account of the spreading habit of most of the forms, rows appreciably closer than this would be somewhat difficult to cultivate after the first two or three years.

HILLS.

In some respects *Medicago falcata* is better suited to cultivation in widely spaced hills than *Medicago sativa.* The larger development of the crown of the former is an important factor in this connection.

At Brookings, plants of S. P. I. Nos. 20717 and 20725 in hills 24 by 36 inches spread to such an extent in four years that it became impossible to cultivate between the rows. In the case of these introductions the diameters of the crowns were fully twice those of the broadest crowns of the ordinary alfalfas. While these numbers represent the most spreading forms of the species, even the most erect forms produced a very large crown under such conditions. (Fig. 23.) It appears quite probable that when grown in hills the best hay forms of *Medicago falcata* will produce a better yield than *Medicago sativa* where conditions are favorable for only one cutting of the latter. However, under conditions such as ordinarily obtain at Highmore,

FIG. 22.—A broadcast plat of *Medicago falcata* in which awnless brome-grass (*Bromus inermis*) has volunteered. The brome-grass has a tendency to cause the *Medicago falcata* to grow more erectly.

the data indicate that *Medicago sativa*, even in cultivated rows or broadcast, will produce a heavier yield than *Medicago falcata* grown in hills 44 by 44 inches. At Brookings, S. P. I. Nos. 20717 and 24452 produced a heavier yield when the plants were grown in hills 24 by 36 inches than when grown in broadcast plats. On the other hand, common alfalfa produced a heavier yield in broadcast stands than in cultivated rows or hills.

TRANSPLANTING.

The transplanting of alfalfa has been suggested as a partial solution of alfalfa problems in sections having severe conditions of cold and drought. There are serious economic difficulties in the general adoption by farmers of this method of culture. Since economic conditions are constantly changing and are nowhere precisely the same, it seems well to give consideration to transplanting or to any other cultural method that offers even remote possibilities. The cost incident to transplanting practically restricts the method to planting in hills. As previously pointed out, *Medicago falcata* lends itself well to this type of planting on account of its ability to spread and produce a broad crown. In addition, it apparently bears resetting better than *Medicago sativa*, which is a very important consideration. Should transplanting ever become popular, it will offer an opportunity for selected strains of *Medicago falcata* to compete with the better varieties of *Medicago sativa*.

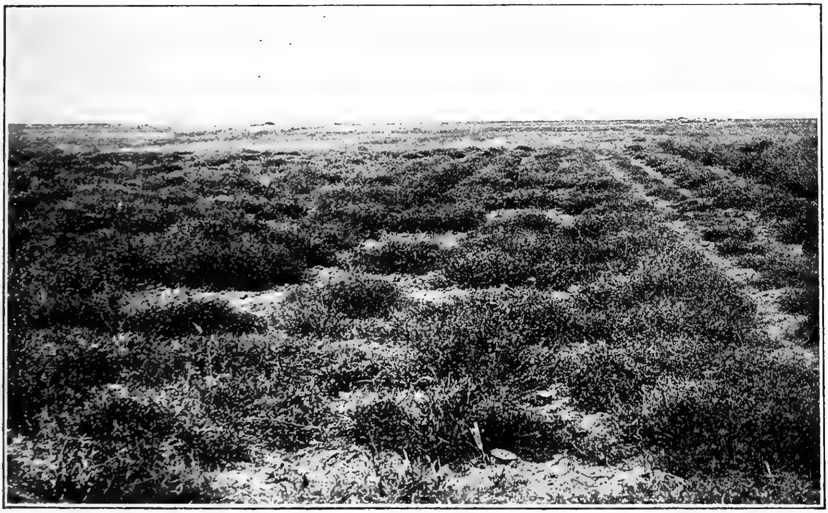


FIG. 23.—*Medicago falcata* planted in hills 42 by 42 inches. When planted in this way the crowns make a very large development.

SEEDING ON THE RANGE.

The possibility of utilizing *Medicago falcata* in native pastures and on the range has appealed to many of the investigators who are familiar with the habits of this species in its native habitat. Both Hansen and Meyer, who have studied it in Russia and Siberia, are convinced that it can be made a valuable addition to our list of native grazing plants, especially in the northern portion of our Great Plains area. Since 1909 various tests have been conducted with it on unbroken sod. In a majority of cases the results have been of a somewhat negative character, although in comparatively few were the sowings a total failure. In the spring of 1912 rod-square plats in the native pastures of the Highmore substation were sown with the most promising forms of the species, with Grimm alfalfa in check plats. The seed was scattered upon the surface of the ground without any preparation of the soil. In 1913 a few small plants of *Medicago falcata* were in evidence, but their ability to maintain themselves at that time seemed very doubtful. However, in 1914 some of the plants had reached a considerable size and promised to become well established in the prairie sod. Apparently, only a very few plants of the Grimm alfalfa developed. Similar experiments are being conducted at many points throughout the Great Plains region. While the results so far are not particularly encouraging, the method is worthy of trial. Plants of *Medicago falcata* are normally found so sparsely scattered in other native vegetation in those parts of Europe and Asia where the species grows that they do not furnish any great amount of grazing per unit area. However, in a new environment, such as this country offers, it is possible that the species may become much more aggressive than it is in its native habitat.

POSSIBILITIES IN SELECTION AND HYBRIDIZATION.

While there are important agronomic data still needed on *Medicago falcata* as it is introduced from Europe and Asia, it is reasonably certain that the greatest possibilities of the species lie in breeding for the development of hardy and drought-resisting strains. Selection alone offers only limited possibilities, but hybridization and selection together offer abundant opportunities for originating new and improved varieties.

SELECTION.

As they were introduced, the lots of seed of *Medicago falcata* contained a mixture of forms, and while certain of them showed considerable uniformity the majority represented such a complex that it was scarcely possible to determine the predominating type. There is already conclusive proof of the value of selection in the separation and development of superior strains of this species. Forms exist that approach *Medicago sativa* in erectness and general agronomic characteristics, and by the propagation of such forms it is possible to establish a fairly uniform strain superior to the mixed lots originally introduced.

There are several areas in this country where dry-land farming is practiced that are unfavorable for the production of more than one cutting of alfalfa a season. If the crop can be grown profitably in these sections, even if only one cutting is produced, there may be use for select strains of *Medicago falcata*. However, under the above conditions pure strains of *Medicago falcata* will meet with keen competition from hybrids of *Medicago sativa* and *Medicago falcata*, since certain of the hybrids probably are nearly or quite as resistant to cold and drought as are the pure strains of *Medicago falcata*. Furthermore, they possess the additional advantage of yielding more abundantly. Unless a pure strain of *Medicago falcata* that will produce two or more cuttings in a season can be developed by selection, this method alone is limited in the scope of its usefulness.

When the need arrives for special strains of alfalfa for pasturage it doubtless will be met to some extent by selection from the low-growing and spreading forms of the species. Hybrid strains might have some difficulty in competing successfully with such selections, even though they do not recover quickly after cutting.

HYBRIDIZATION.

While pure strains of *Medicago falcata* for hay and pasture may find a permanent place among our cultivated crops, it is not in this rôle that the species promises to become important. Its greatest value lies in its ability to form fertile hybrids with *Medicago sativa*. This conclusion has been quite generally reached by those who have investigated the species carefully and who appreciate the important part that it has taken in the development of our commercial strains of alfalfa. An examination of early botanical and agricultural literature indicates that it was common in Europe many centuries ago, and probably it has hybridized with *Medicago sativa* since an indefinitely remote date. The effect of this on our commercial strains of alfalfa is difficult to estimate. The origin of our more or less distinct varieties of commercial alfalfa has not as yet been well determined. The readily recognizable hybrids have been roughly assigned to what is known as the variegated group and it has been assumed that those which do not show variegation in color of flowers are pure strains. Careful investigations may reveal at least a trace of *Medicago falcata* in the parentage of many distinct commercial varieties. Its part in the development of the well-known Grimm alfalfa has been fully discussed and generally recognized. Instead of indicating the possibility of developing better strains by hybridization, this recognition has had a tendency to create the impression that the chances of producing anything better than the Grimm variety through hybridization are very remote. There is, however, good ground for taking the opposite view.

The stock from which Grimm alfalfa originated came from Baden, Germany, and in all probability had been produced there for many seed generations. The hybridization which took place in the development of this stock was doubtless a more or less continuous process in which the local forms of *Medicago falcata* were the only forms concerned. There are numerous forms not found in that portion of Europe, and the possibility of obtaining hybrids between certain of these and good forms of *Medicago sativa* seems to offer a particularly promising field.

With the Grimm variety as an example of what may be accomplished through the aid of the southern forms of *Medicago falcata*, even better results may be expected from the crossing of good northern forms with *Medicago sativa*. Some very promising hybrids have already been made between the Peruvian and Arabian alfalfas and a fairly erect type of *Medicago falcata* similar to the form illustrated in figure 17. These hybrids combine valuable characters, including to a rather remarkable degree the quick recovery and growth of the Peruvian and Arabian varieties and the low crown and abundant tillering of *Medicago falcata*. Furthermore, they have proved to be reasonably hardy at Highmore. The advantages of such hybrids can readily be appreciated.

The proliferating root character, as found in certain forms of *Medicago falcata*, has only recently been observed in this country. By the use of this character, high-yielding strains may be originated that will be especially resistant to severe climatic conditions and actually aggressive on soils of fairly loose texture.

The above are only a few of the possibilities that are offered to the plant breeder by this diverse species, and those who fail to see beyond its agronomic defects as it exists in its natural state are missing an opportunity in the field of plant breeding.

ARTIFICIAL AND NATURAL HYBRIDIZATION.

There are two ways of utilizing *Medicago falcata* in the development of hybrid strains of alfalfa; namely, in the making of natural and of artificial hybrids. The latter is the more definite and promising method, but the former unquestionably offers possibilities. In the making of artificial hybrids both parents may be carefully chosen and rigid selection made in the progeny. While the expense incident to this method is considerable, satisfactory results can be secured from it in a much shorter time than from the latter method. Pollination by artificial means is easily accomplished, either by what is termed the depollination method or by tripping the flower of the plant selected for the female parent on a knife blade or similar instrument upon which pollen from another plant has been collected. On account of its comparative simplicity the latter method is generally preferred. It appears to be true that the pollen of *Medicago falcata* is prepotent over that of *Medicago sativa* on the stigmas of the latter, and vice versa. At any rate, there is very little difficulty in effecting reciprocal crosses between the two species. Methods of pollination have been fully discussed in bulletins of the Department of Agriculture (*46*) and other institutions.

The fact that the hybridization which has produced the variegated commercial strains of alfalfa has been the result of natural agencies leads to the belief that with careful work still better results may be obtained. In sections where climatic conditions are reasonably favorable for seed production, hybrid strains could soon be developed by establishing a few plants of *Medicago falcata* in a field of *Medicago sativa* or in the fence rows and margins of the fields. A heterogeneous collection of hybrids would develop from this method, but with the assistance of natural eliminating agencies appreciable good would result, especially in sections where drought and winterkilling are important factors.

DIFFICULTIES IN ESTABLISHING NEW STRAINS.

The difficulties in establishing a new variety or strain of alfalfa must not be underestimated. There are three important factors that seriously interfere with the maintenance of pure strains of this crop; namely, the open fertilization of the flowers, the lack of distinct varietal differences in seed and other botanical characters, and the mixing of the seed either as the result of careless or unscrupulous handling. With regard to the first-mentioned handicap it has been suggested that only one variety of alfalfa be grown in a community, and in this way the chances for the contamination of the strain through the medium of cross-fertilization with other strains would be reduced to a minimum. Under present conditions, this plan is not feasible, since it would be difficult, if not quite impossible, to get farmers to organize properly for such a purpose.

A wide difference of opinion exists as to the effect on the characters of a given strain of the cross-fertilization that takes place in alfalfa under average field conditions. Brand (*13*) offers it as an explanation for the failure of a certain lot of Grimm alfalfa to survive the winter to the same degree as other lots of this variety tested with it, even though it had been directly exposed to cross-pollination for only one seed generation. Oliver[1] is likewise of the opinion that the cross-pollination that normally takes place in alfalfa is a serious detriment to the establishment of superior strains, and he cites the case of Peruvian alfalfa in the Southwest in this connection. Field observations, however, do not seem to justify the belief that the Peruvian variety will soon lose its identity through cross-fertilization in the Southwest. In fact, there is no appreciable evidence that deterioration has occurred from this cause. That strains of alfalfa will lose their distinct characteristics as the result of continued crossing with other strains can scarcely be questioned, some strains perhaps being more susceptible than others. It also appears to be true that it is a mistake to attempt to breed alfalfa along narrow lines. Taking everything into consideration, it is safe to conclude that the first of the three factors mentioned is the least important.

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[1] In an unpublished paper.

Lack of distinct differences in the appearance of varieties, especially in seed characters, handicaps the promotion of new alfalfas. Striking differences excite interest on the part of farmers, while lack of them affords opportunity for fraudulent practices in connection with the sale of seed. Unless a variety is markedly different from one that is commonly grown, either in general appearance or in adaptation to certain conditions, farmers are not apt to take more than a passing interest in it. The real differences between varieties are not always visible. Hardiness and drought resistance, while highly important characteristics, can not be readily determined. Fortunately, the so-called variegated group, containing readily recognizable hybrid alfalfas and including our hardiest and most drought-resistant strains, is sufficiently distinct from the common, Peruvian, and Arabian groups to be recognized by those who are familiar with these groups. This lessens the confusion and has a tendency to discourage to some extent the practice of seed adulteration and misbranding.

There are at present several commercial strains belonging to the variegated group, which complicates to some extent the establishment of new strains of this broad group. However, the newly created varieties resulting from a cross between *Medicago sativa* and *Medicago falcata* have a preponderance of variegated flowers unless selected to a narrow type, and this assists in distinguishing such strains from the Grimm and similar older strains.

Careless planting, harvesting, and cleaning, and, most important of all, the willful substitution and adulteration of seed, soon undo the work of careful breeding. These are the most serious handicaps to the permanency of a new and superior variety. A considerable degree of carelessness is certain to result, and the high price at which seed of new varieties commonly is held offers a strong inducement for fraud. Regardless of the care that has been taken and the warnings that have been issued, there are thousands of pounds of seed of other varieties sold annually under the name of Grimm. Properly drafted and administered seed-control laws assist in keeping down such practices, but in many cases positive proof of fraud can not be produced until after the harm has been done.

Since it would seem that the life of a distinct and superior variety of alfalfa under our present conditions is not long, it is more advantageous to develop continuously new varieties than to endeavor to perpetuate pure stocks of the old ones. This leaves a large field for the various forms of *Medicago falcata*. Even if the hybrid strains that are now used can not be improved upon, there will be need for new ones to take their place when they have lost their identity through mixing with other strains.

PRESENT AGRONOMIC STATUS.

The investigations of the Department of Agriculture on a large number of forms of *Medicago falcata* during the past eight years have not determined definitely their agricultural status, but they indicate quite clearly the rôles which they may be expected to fill while our economic conditions remain substantially as they are at present. In an endeavor to make clear the agricultural status of these new alfalfas as it appears at this time, a summary is here presented, in which are set forth the important difficulties in the way of their utilization, together with a brief discussion of their advantages and possibilities as cultivated forage crops.

Slow recovery after cutting, resulting in the production of only one crop of hay in a normal season, is a characteristic of all the forms of the species under observation, with the possible exception of certain introductions from India. This is perhaps the chief handicap to their becoming generally cultivated, as it limits the yield to a point of doubtful profit. The decumbent habit of most forms is not characteristic of all, there being some that are sufficiently erect to be harvested successfully by field machinery. Lack of erectness, therefore, can not be considered as an objection to the species as a whole.

A difficulty, however, of no small importance is found in the seed habits of this species. The quantity of seed that can be successfully harvested under the most favorable conditions is small compared with that from common alfalfa, and the percentage of hard seed is so high as to require a considerable quantity at the time of seeding to secure a satisfactory stand. The high percentage of hard seed, together with the slow growth of the seedlings, makes it difficult to obtain a good stand and maintain it against weeds, especially under conditions of broadcast seeding. The minor objections to *Medicago falcata* as a cultivated crop have already been pointed out and need not be dwelt upon further.

The systematic introduction of the species was prompted by a desire to find strains of alfalfa sufficiently hardy and drought resistant to grow successfully in the colder and drier portions of the country. Apparently, many of these forms are able to withstand severe conditions of cold and drought, to the extent at least of maintaining an existence, and in much of the area where dry-land farming is now practiced the best strains will produce one cutting in a season from planting in hills and rows, if not from broadcast seedings.

There are two very important questions that present themselves in this connection. (1) Will these new alfalfas produce one good cutting annually in sections now considered too dry for successful agriculture? No encouraging answer can be given to this question at the present time. (2) Will the yield from the one cutting that they may be expected to produce be sufficiently large to make their extensive culture profitable? The answer in this case is not very optimistic. It is quite probable, however, that conditions exist under which a limited area of alfalfa would be valuable, even where only one cutting, of a ton or somewhat less per acre, is all that could be expected in a season. If this be true, certain of the best hay-producing strains of *Medicago falcata* may have an advantage under such conditions over the best strains of *Medicago sativa* that are now available, not only because of their hardiness and drought resistance, but also because of their apparent ability to produce a somewhat heavier yield from the one cutting. But whether they possess a material advantage over the best hybrids of the two species is by no means certain.

Economic conditions are slowly changing. The feasibility of establishing alfalfa fields in dry areas where agriculture is precarious, either by seeding or by the transplanting of seedling plants, is now being considered. The varieties of *Medicago falcata* lend themselves well to this type of culture. In widely spaced hills the individual plants make a very large development, and the young plants bear transplanting better than plants of *Medicago sativa*. The time for the extensive culture of alfalfa in hills for forage is probably very far distant, as is the extensive growing of the crop under any system of culture in sections where only one cutting can be procured each season, so that the alfalfa problem is by no means solved by the securing of so-called hardy and drought-resistant strains. To become generally useful these alfalfas must produce a sufficient yield to be profitable and to compete with the cereals and other crops that can be utilized for forage.

To what extent *Medicago falcata* will be found of value in connection with the improvement of our native pastures and ranges can not definitely be stated at this time. The field is a very broad one, and critical data are still wanting. The results of investigations to date, however, do not warrant any considerable degree of optimism. Experimental plantings on native sod have been established, but the plants so far have failed to exhibit the aggressiveness that is necessary to make them valuable. Under cultivation in the more favorable sections the species offers somewhat greater promise. Its forms possess certain characteristics that fit them for pasturage purposes. The spreading habit and development of rhizomes and proliferating roots enable them to endure grazing and trampling to a considerable degree. For pasture, as well as for the production of hay, however, their slow recovery makes it very doubtful whether they will be able to compete successfully with the better hybrid strains.

It is in the field of plant breeding that *Medicago falcata* offers its greatest usefulness, and in this field its possibilities have been only partially developed. Our most hardy and drought-resistant alfalfas have been developed as a result of natural hybridization with *Medicago sativa* and subsequent natural selection. By the artificial crossing of *Medicago sativa* with forms of *Medicago falcata* that possess striking and valuable characteristics, such as are offered by the abundant material now available, it has already been demonstrated quite definitely that strains of alfalfa appreciably superior to even the best now available can be originated. Furthermore, it is now generally recognized that the only practicable way of maintaining superior strains is by developing new ones continuously. The whole field of investigation so far as *Medicago falcata* is concerned is still open to those who are amply equipped, both financially and by training, to do careful investigational work. It is believed that the burden of the development of this species to the point where it can be successfully utilized should fall on the United States Department of Agriculture, the State agricultural experiment stations, and similar institutions, and not on the farmer. Furthermore, the farmer is advised to go to no great expense in procuring seed of the forms of the species now available, since the returns which he might reasonably expect will scarcely be commensurate with the expense involved.

The breeding work is being done as rapidly as possible, and just as soon as it has reached the point where promising strains, either pure or of hybrid origin, have been perfected, they will be made available to the public.

SUMMARY.

The first importation of *Medicago falcata* into the United States of which there is a record was made in 1897. The first systematic introductions for the purpose of utilizing the species as a cultivated forage crop were made in 1906 by Prof. N. E. Hansen under the auspices of the United States Department of Agriculture. Since that date many lots of seed representing various forms of the species have been introduced by Prof. Hansen, Mr. Frank N. Meyer, and various others. Approximately fifty lots have been introduced, mostly from Russia and Siberia.

At the present time *Medicago falcata* is found growing without cultivation in most parts of Europe and the western two-thirds of Asia. Over a large portion of this area it probably is indigenous. It is found throughout a wide range of soil and climatic conditions and at depressions and elevations ranging from below sea level to 13,000 feet above. It is much wider in its adaptations than *Medicago sativa*.

The species was recognized by botanists early in the history of modern botany, if not long before. Recent botanists differ somewhat with regard to its taxonomic relationship to *Medicago sativa.* Some give it the rank of a true species, while others regard it as a variety or subspecies of the latter. The natural relationship of the two, however, is quite clearly shown by the readiness with which they hybridize and the fertility of their hybrids.

It is an extremely variable species, many forms of which are difficult to classify satisfactorily on account of their varying combinations of characters and the difficulty of determining whether they are of pure or hybrid origin. A classification or grouping has been attempted in this paper largely upon the basis of habit of growth. Four groups have been established, ranging in habit from prostrate to almost erect. The first two are referred to as pasture groups, as they are not sufficiently erect to be harvested satisfactorily for hay by machinery. The last two are sufficiently erect to be harvested for hay and are referred to as hay groups.

Botanists have named and described several varieties of the species, many of which have proved to be hybrids of *Medicago falcata* and *Medicago sativa.*

Medicago falcata has never been extensively cultivated in Europe or Asia, although it has been utilized as a wild forage plant since a very early date. Many attempts have been made to grow it under cultivation in Europe, but so far as can be found it is now being cultivated only in India and, possibly, to a very limited extent in southeastern Russia and Chinese Turkestan.

Numerous common names have been proposed for the species, but so far none is satisfactory. The name by which it is most generally known in this country is yellow-flowered alfalfa. It is probable that this name will finally be adopted.

The erect forms of *Medicago falcata* resemble very closely those of *Medicago sativa* in their mass effect, but on an average they produce a heavier yield in comparison with their bulk, partly because of the more numerous stems and partly because of the texture of their herbage. Under similar conditions of soil and stand of plants the best strains of *Medicago falcata* frequently outyield the best varieties of *Medicago sativa* for the first cutting of the season.

A very serious drawback to the general utilization of *Medicago falcata* as a cultivated forage crop is its inability to recover quickly after cutting. Under conditions such as exist in the West and Northwest, where it appears to offer its greatest possibilities, it can be depended upon to make only one crop in a season. It produces seed sparingly and does not hold it as retentively as does *Medicago sativa.* This is also a serious handicap to its use as a cultivated crop.

The natural range of distribution of the species, its specific adaptations, and its behavior under field conditions in this country warrant the conclusion that it is relatively hardy and drought resistant.

Chemical analyses and general feeding tests indicate that it is approximately as valuable from a feeding standpoint as common alfalfa.

The cultural requirements of *Medicago falcata* appear to be much the same as those of *Medicago sativa*. On account of the hard seed which the former produces and the slow growth of the young plants it is difficult to secure a satisfactory stand from seeding, either broadcast or in rows. When grown in broadcast stands the procumbent forms are inclined to be more nearly erect than when grown in rows or hills. The plants of this species bear transplanting better than do those of *Medicago sativa*.

Data from broadcast plats of *Medicago falcata* and *Medicago sativa* indicate that in seasons when only one cutting of the latter can be procured the former produces the heavier yield, but in favorable seasons, when two or more cuttings can be procured, the latter excels appreciably in yield.

Sowings of *Medicago falcata* have been made on unbroken native sod land and a fair stand of plants secured. The plants appear to lack sufficient aggressiveness to make them really valuable under such conditions.

The greatest possibilities offered by the species appear to be in the field of selection and hybridization. In a few cases it is probable that the development of promising pure strains by selection will prove to be advantageous. As the result of hybridizing with *Medicago sativa* and subsequent selection it is believed that superior varieties of alfalfa can be developed and that the greatest value of the species is for this purpose.

Much time and effort will be required before *Medicago falcata* will be ready for general cultivation.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 429

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER. February 28, 1917

LIFE HISTORY OF THE CODLING MOTH IN THE PECOS VALLEY, NEW MEXICO.

By A. L. QUAINTANCE, *Entomologist in Charge of Deciduous Fruit Insect Investigations,* and E. W. GEYER, *Scientific Assistant.*

CONTENTS.

	Page.
Introduction	1
Definition of terms used	2
Seasonal-history studies of 1912	3
The spring brood	3
The first generation	6
The second generation	13
The third generation	25
Seasonal history of the codling moth during 1912	31
Band-record larvæ of 1912	32
Seasonal-history studies of 1913	34
Source of rearing material	34
Method of procedure	35
Seasonal-history studies of 1913—Continued.	
The spring brood	36
The first generation	42
Egg deposition by individual moths	50
The second generation	56
The third generation	68
The fourth generation	78
Miscellaneous emergence of moths	79
Band records of 1913	80
Seasonal history of the codling moth during 1913	87
Summary	87

INTRODUCTION.

During the past four years the Bureau of Entomology has maintained a field laboratory at Roswell, N. Mex., for the purpose of investigating the life history and habits of the codling moth, *Carpocapsa pomonella* L., under semiarid conditions in the Southwest, and for the purpose of carrying out experiments in orchards for its control. Especial attention was given to the life history of the insect in that region during 1912 and 1913 in addition to extensive spraying operations in orchards. During 1914 and 1915 the work has been limited to orchard experiments.

The Pecos Valley, in the vicinity of Roswell, comprises an important fruit-growing section especially devoted to the cultivation of apples and pears. The codling moth in this region, due to the mild climate, is able to develop three and probably four broods of larvæ each season and is hence extremely injurious. The present investigation by the Bureau of Entomology will furnish needed information to the orchardists of the Pecos Valley in New Mexico for the control of the codling moth, and the results should be applicable to similar regions in the Southwest generally.

This bulletin deals with the life history and habits of the codling moth, giving the results of observations in 1912 and 1913. Results of spraying operations during those years have been given in Bulletin No. 88 of this department. Subsequent experiments in orchards will be reserved for a later publication.

During the season of 1912 investigations were conducted by Mr. A. G. Hammar, assisted by Mr. E. R. Van Leeuwen. Mr. Hammar was also in charge of the work during 1913 and was assisted by Mr. L. L. Scott and the junior author. Messrs. R. J. Fiske and H. G. Ingerson rendered valuable assistance in connection with the preparation of the tables in the present paper. Owing to the death of Mr. Hammar it devolved upon the writers to prepare for publication the results of his studies and experiments.

DEFINITION OF TERMS USED.

The terms used herein are practically identical with those employed in recent former publications of the Bureau of Entomology on the codling moth. Thus the term "brood" is used in speaking of individuals of one generation of any stage, as egg, larva, or pupa. A "generation" is considered to begin with the egg stage and to terminate with the moth, or imago, stage of the same generation, thus including all the stages of the life cycle. The "complete life cycle" includes the time from the deposition of the egg of one generation to the time of deposition of the egg of the next generation.

Since the wintering larvæ of the codling moth in the Pecos Valley (as well as in other localities where there is even a partial second brood of larvæ) are from the different broods produced throughout the same season, they are referred to collectively as "wintering larvæ," and include all the larvæ which do not transform the same season as hatched.

Similarly, the overwintering larvæ when transformed in the spring to pupæ may be suitably referred to as "spring pupæ" and the resulting moths as "spring moths."

The terms used in designating the separate stages may be defined as follows:

Wintering larvæ may include larvæ of the first, second, third, and fourth broods of the preceding season.

The spring brood of pupæ include pupæ resulting from overwintering larvæ.

The spring brood of moths include moths emerging from the spring brood of pupæ.

The first generation includes:

- *The first brood of eggs;*
- *The first brood of larvæ,* which includes both transforming larvæ and wintering larvæ;
- *The first brood of pupæ,* resulting from transforming larvæ;
- *The first brood of moths,* which emerge from transforming pupæ of the same generation.

The second generation includes:
- *The second brood of eggs;*
- *The second brood of larvæ,* which includes both transforming larvæ and wintering larvæ;
- *The second brood of pupæ,* resulting from transforming larvæ;
- *The second brood of moths,* which emerge from pupæ of the same generation.

The third generation includes:
- *The third brood of eggs;*
- *The third brood of larvæ,* which includes both transforming larvæ and wintering larvæ;
- *The third brood of pupæ,* resulting from the transforming larvæ;
- *The third brood of moths,* which emerge from pupæ of the same generation.

The fourth generation (not complete) includes:
- *The fourth brood of eggs;*
- *The fourth brood of larvæ;* none of these larvæ transform until the following spring.

SEASONAL-HISTORY STUDIES OF 1912.

The rearing material in the spring of 1912 consisted of a considerable number of overwintering larvæ which had been collected at random in near-by orchards. About 500 larvæ were collected in January and early March, and later in March and in early April several thousand more were secured from the same source. Some 500 larvæ were transferred to "pupation sticks" (figs. 6, 7) for pupal observation, but the mortality among them was unduly high and many of them failed to withstand the transfer and reconstruction of cocoons. The overwintering larvæ in the spring were found in poor condition, many being small and feeble, and even in the field a number of dead ones were found in the cocoons.

A supply of larvæ was transferred from the field station at Douglas, Mich., both for the purpose of introducing the parasitic hymenopterous fly *Ascogaster carpocapsae* Vier., and to compare the time of emergence of the moths with specimens native to Roswell, N. Mex.—a point of interest in view of the frequent extensive shipment of larvæ into localities of variable conditions.

THE SPRING BROOD.

PUPATION OF SPRING BROOD.

The few observations taken on the pupal stage of the spring brood are not sufficient for conclusions as to the exact length of the pupal stage, nor the degree of variation in the spring brood of pupæ. The earliest pupa was found in the field March 15, and the earliest moth appeared in cages from field-collected material April 12, the pupation period being approximately 31 days. Fully 50 per cent of the insects were pupæ in the field by April 2, and on May 5 about one-half of the moths had emerged, which shows that the pupal stage for most individuals was about one month. The pupal stage during the latter half of the pupal period was much shorter. Records of seven individuals from March 22 to May 14, give an average of 24.4 days for the pupal stage.

EMERGENCE OF SPRING BROOD OF MOTHS.

The time for emergence of moths from Roswell-collected rearing material was contrasted with that brought from Douglas, Mich., and it was found that from the Roswell material moths emerged several days earlier than from material introduced from a more northern location, but were less regular in the number and time of appearance, although covering almost the same length of time. The Michigan moths showed a marked maximum of emergence about May 1; otherwise considerable similarity is noted. In this connection 542 moths were reared from the New Mexico material and 506 from the lot from Michigan. The records for emergence for the spring brood are given in Table I.[1]

TABLE I.—*Time of emergence of spring brood of codling moth, Roswell, N. Mex., in comparison with emergence of moths from material from Douglas, Mich., 1912. (See fig. 1.)*

Date of emergence.	Number of moths emerging.			Date of emergence.	Number of moths emerging.		
	Roswell.	Douglas.	Total.		Roswell.	Douglas.	Total.
Apr. 12	4	....	4	May 7	36	28	64
13	1	....	1	8	19	15	34
14	1	....	1	9	28	12	40
15	0	....	0	10	13	9	22
16	1	....	1	11	12	9	21
17	5	....	5	12	25	10	35
18	5	....	5	13	23	16	39
19	4	....	4	14	4	0	4
20	15	....	15	15	5	0	5
21	13	....	13	16	24	10	34
22	10	....	10	17	12	4	16
23	12	1	13	18	14	6	20
24	26	2	28	19	8	6	14
25	27	4	31	20	8	3	11
26	26	6	32	21	8	5	13
27	13	4	17	22	4	0	4
28	8	15	23	23	2	2	4
29	11	36	47	24	0	....	0
30	10	48	58	25	0	....	0
May 1	32	46	78	26	2	....	2
2	11	64	75	27	0	....	0
3	11	62	73	28	1	....	1
4	9	19	28				
5	16	27	43	Total	542	506	1,048
6	23	37	60				

EGG DEPOSITION OF SPRING BROOD OF MOTHS.

In order to secure deposition records on the spring brood, moths were confined in cages after the first emergence on April 21. From the 13 moths issuing in cage No. 1, bearing the above date of emergence, the first oviposition occurred April 25—four days later—and oviposition continued for a period of three days, the last deposition in cage No. 1 occurring April 28, seven days after emergence. The last oviposition recorded for the entire period covered by observations

[1] EXPLANATORY NOTE.—It may be well to explain here that each table in this publication should be considered a unit. Consecutive or successive tables are not necessarily continuations of the life history of the same individuals. For example, it will be noted that Table XIV is a record of the length of feeding period of 489 transforming larvæ of the second generation, while Table XVI includes observations on the length of the cocooning period of only 282 larvæ of this generation. Differences of this character may be due to natural or artificial causes, such as death of the insects, accidental injury, the removal of specimens for other purposes, etc.

occurred June 2. Hence the period of oviposition covered practically 38 days.

By a study of Table II it will be noted that the average number of days from the time of emergence to the time of first oviposition was 4.4 days; the maximum time 7 days, and the minimum time 2 days. The average duration of the oviposition period was 5.95 days; the

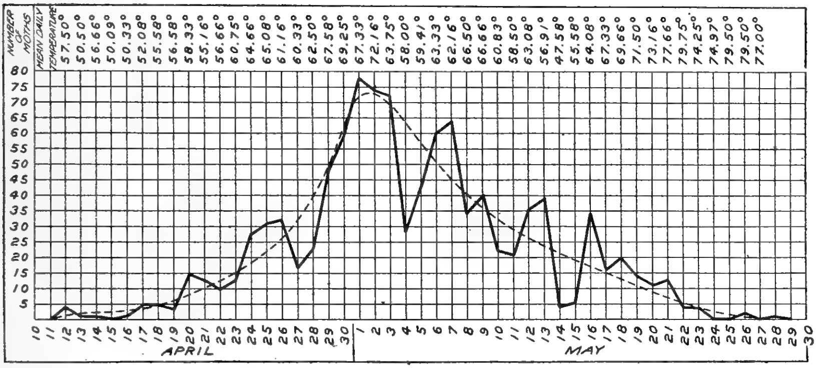

FIG. 1.—Emergence curve of the spring brood of the codling moth, Roswell, N. Mex., 1912. (Original.)

maximum 17 days, and the minimum 1 day. The average number of days from the date of moth emergence to the date of last oviposition was 10.39 days; the maximum, 21 days; and the minimum, 4 days.

TABLE II.—*Egg deposition of codling moths of the spring brood at Roswell, N. Mex., 1912.*

Cage No.	Number of moths.	Date of— Emergence.	Date of— First oviposition.	Date of— Last oviposition.	Number of days— Before first oviposition.	Number of days— Of oviposition.	Number of days— From date of emergence to last oviposition.
1	13	Apr. 21	Apr. 25	Apr. 28	4	3	7
2	10	22	27	29	5	2	7
3	12	23	28	30	5	2	7
4	26	24	26	30	2	4	6
5	27	25	29	....	4	....	....
6	25	26	May 3	May 7	7	4	11
7	24	28	2	8	4	6	10
8	43	29	2	8	3	6	9
9	58	30	4	21	4	17	21
10	60	May 1	8	18	7	10	17
11	71	2	7	18	5	11	16
12	76	3	7	18	4	11	15
13	37	5	9	18	4	9	13
14	59	6	9	21	3	12	15
15	66	7	10	18	3	8	11
16	31	8	10	16	2	6	8
17	28	9	15	18	6	3	9
18	17	10	17	20	7	3	10
19	30	11	16	21	5	5	10
20	23	13	18	21	5	3	8
21	11	17	23	26	6	3	9
22	18	18	20	22	2	2	4
23	19	19	22	23	3	1	4
24	12	21	27	June 2	6	6	12
Average					4.4	5.95	10.39
Maximum					7	17	21
Minimum					2	1	4

LENGTH OF LIFE OF MOTHS.

Observations were made on the length of life of 335 male moths and 393 female moths. The average life of the male moths was 6.7 days; of the female 8.47 days. The maximum length of life of the male moth was 20 days and of the female 22 days. The minimum number of days for each sex was identical—2 days.

The records of these observations may be found in Table III.

TABLE III.—*Length of life of 728 individual male and female codling moths of the spring brood, Roswell, N. Mex., 1912.*

Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
Days.		*Days.*		*Days.*		*Days.*	
2	2	2	3	13	2	13	13
3	11	3	10	14	1	14	15
4	28	4	24	18	1	15	5
5	73	5	34	20	1	16	3
6	72	6	48			17	3
7	42	7	51			18	2
8	41	8	54			19	3
9	24	9	47			20	3
10	18	10	37			22	1
11	14	11	23				
12	5	12	14		335		393

Average length of life of male moths, 6.7 days.
Average length of life of female moths, 8.47 days.
Maximum length of life of male moths, 20 days.
Maximum length of life of female moths, 22 days.
Minimum length of life of male moths, 2 days.
Minimum length of life of female moths, 2 days.

THE FIRST GENERATION.

THE FIRST BROOD OF EGGS.

Length of incubation.—Observations on the length of incubation covered a period of one month, extending from April 26 until May 26, being the time when the eggs of this generation occurred in the field in greatest numbers.

The average length of time from the date of deposition until the appearance of the red ring was 4.2 days; the maximum, 7 days; the minimum, 2 days. The average length of the duration of the red ring was 2.47 days; the maximum, 5 days; minimum, 1 day. For the duration of the black spot is found an average of 2.36 days, while the maximum and minimum periods are identical with the corresponding periods of the red ring.

For the period of time covering the duration of incubation, or the time from date of deposition to date of hatching, an average of 9.05 days is found. The maximum is 13 days; minimum, 5 days. These records may be found in Table IV.

TABLE IV.—*Length of incubation period of eggs of the first brood of the codling moth, Roswell, N. Mex., 1912.*

Observation No.	Date of egg deposition.	Date of— Red ring.	Date of— Black spot.	Date of— Hatching.	Duration of— Red ring.	Duration of— Black spot.	Duration of— Incubation.
					Days.	*Days.*	*Days.*
1	Apr. 26	Apr. 29	May 4	May 6	5	2	10
2	26	29	4	7	5	3	11
3	26	29	4	8	5	4	12
4	26	29	4	9	5	5	13
5	28	May 3	5	7	2	2	9
6	28	3	5	8	2	3	10
7	28	3	5	9	2	4	11
8	29	3	5	7	2	2	8
9	29	3	5	8	2	3	9
10	29	3	5	9	2	4	10
11	May 2	6	9	10	3	1	8
12	2	6	9	12	3	2	10
13	3	7	10	12	3	2	9
14	3	7	10	13	3	3	10
15	3	7	10	14	3	4	11
16	4	10	12	14	2	2	10
17	4	10	12	15	2	3	11
18	4	10	12	16	2	4	12
19	4	10	12	17	2	5	13
20	5	12	14	16	2	2	11
21	5	12	14	17	2	3	12
22	6	12	15	17	3	2	11
23	6	12	15	19	3	4	13
24	8	14	18	19	4	1	11
25	8	14	18	20	4	2	12
26	9	15	18	20	3	2	11
27	9	15	18	21	3	3	12
28	10	16	19	21	3	2	11
29	10	16	19	22	3	3	12
30	11	18	20	21	2	1	10
31	12	18	20	21	2	1	9
32	12	18	20	22	2	2	10
33	13	19	21	23	2	2	10
34	13	19	21	24	2	3	11
35	15	18	20	22	2	2	7
36	15	18	20	22	2	2	7
37	16	19	21	22	2	1	6
38	16	19	21	23	2	2	7
39	17	20	22	23	2	1	6
40	17	20	22	24	2	2	7
41	18	21	23	24	2	1	6
42	18	21	23	25	2	2	7
43	19	23	24	25	1	1	6
44	20	22	24	25	2	1	5
45	20	22	24	26	2	2	6
46	21	23	25	26	2	1	5
47	21	23	25	27	2	2	6
48	22	24	27	28	3	1	6
49	22	24	27	29	3	2	7
50	23	25	27	29	2	2	6
51	23	25	27	30	2	3	7
52	23	25	27	31	2	4	8
53	27	30	31	June 2	1	2	6
54	27	30	31	3	1	3	7
55	30	June 2	June 4	6	2	2	7
Average					2.47	2.36	9.05
Maximum					5	5	13
Minimum					1	1	5

Time of hatching.—By reference to Table V it will be noted that the earliest first-brood eggs hatched May 7, and hatching continued more or less irregularly until June 2, when the last observation was made. Hence, eggs of the first brood were hatching for a period of 26 days, and were hatching in largest numbers from May 21 to May 26, reaching the maximum number on May 21.

THE FIRST BROOD OF LARVÆ.

Length of feeding period of larvæ—The length of feeding period of larvæ of the first brood was determined from observations with 51 individuals as given in Table V. The average length of feeding was 21.52 days; maximum, 27 days; minimum, 15 days. In this instance the wintering larvæ were not isolated from transforming larvæ of the same brood.

TABLE V.—*Length of feeding period of larvæ of the first brood of the codling moth, Roswell, N. Mex., 1912.*

Date of hatching.	Number of individuals.	Length of feeding in specified days, being the time from hatching of egg to the leaving of fruit by larvæ.													Average days.	Minimum days.	Maximum days.	Total days.
		15	16	17	18	19	20	21	22	23	24	25	26	27				
May 7	2													2	.27	27	27	54
8	1										1				.24	24	24	24
12	3								1	1			1		23.6	22	26	71
17	4							2			1			1	23.25	21	27	93
20	4			1							2	1			22.5	17	25	90
21	18	1	1	2		4	1	3	1	2		1	1	1	20.6	15	27	370
22	2							1		1					22	21	23	44
23	5					1		2				2			22.2	19	25	111
26	9		1		2	1	2	1	2						19.3	16	22	174
30	1									1					23	23	23	23
June 1	1						1								20	20	20	20
2	1										1				24	24	24	24
	51	1	2	3	2	6	4	9	4	5	5	4	2	4	21.52	......	......	1,098

Larval life in the cocoon.—The larval life in the cocoon is generally considered to be the time required for making the cocoons, and is calculated from the time a transforming larva leaves the fruit until the time of pupation. The results of 41 observations show the average time consumed in constructing the cocoon as 5.24 days. The maximum time was 12 days; minimum, 2 days. These records may be found in Table VI.

TABLE VI.—*The making of cocoons by codling-moth larvæ of the first brood, Roswell, N. Mex., 1912.*

Date of leaving fruit.	Number of individuals.	Length of cocooning period in specified days, being the time from the leaving of fruit to the time of pupation.									Average days.	Minimum days.	Maximum days.	Total days.
		2	3	4	5	6	7	10	11	12				
June 2	2					1				1	9	6	12	18
3	3		1			1		1			6.3	3	10	19
4	2				1			1			7.5	5	10	15
5	1								1		11	11	11	11
6	1					1					6	6	6	6
7	1					1					6	6	6	9
8	6			5	1						4.13	4	5	25
9	5			1	2		1		1		6.4	4	11	32
10	1					1					6	6	6	6
11	1		1								3	3	3	3
12	2			2							4	4	4	8
13	4		2	1	1						3.75	3	5	15
14	4	2		1		1					3.5	2	6	14
15	3		1		1		1				5	3	7	15
16	3			2	1						4.3	4	5	13
19	2			1	1						4.5	4	5	9
	41	2	5	13	8	6	2	2	2	1	5.24	2	12	215

THE FIRST BROOD OF PUPÆ.

Time of pupation.—The earliest pupation of the first brood recorded occurred June 1 and the latest July 11. (See Table VII.)

Length of pupal stage.—From a total of 160 individual insects under observation in this connection the results show that the pupal period varied from 9 to 19 days, with an average of 12.11 days. These figures are given in Table VII.

TABLE VII.—*Pupal stage of the first brood of the codling moth, Roswell, N. Mex., 1912.*

Date of pupation.	Number of individuals.	Length of pupal period in specified days, being the time from date of pupation to the emergence of moth.									Average days.	Minimum days.	Maximum days.	Total days.
		9	10	11	12	13	14	15	16	19				
June 1	1					1					13	13	13	13
2	2				2						12	12	12	24
3	1					1					13	13	13	13
4	1				1						12	12	12	12
6	1						1				14	14	14	14
9	5					1	3		1		14.2	13	16	71
10	3						2		1		14.6	14	16	44
11	6			1	1	2		1		1	13.8	11	19	83
12	17			1	11	4	1				12.3	11	14	209
13	5				3	2					12.4	12	13	62
14	18			2	6	6	4				12.6	11	14	228
15	27				9	16	2				12.7	12	14	344
16	12				2	6	1	3			13.4	12	15	161
17	5				2	3					12.6	12	13	63
18	1					1					13	13	13	13
19	2			1	1						11.5	11	12	23
22	11		1	7	3						11.2	10	12	123
23	8		4	3	1						10.6	10	12	85
24	3		2	1							10.3	10	11	31
25	5		4	1							10.2	10	11	51
26	5		2	3							10.6	10	11	53
28	5		4		1						10.4	10	12	52
29	4		3	1							10.2	10	11	41
July 1	5		3	2							10.4	10	11	52
2	2		2								10	10	10	20
5	1	1									9	9	9	9
8	1	1									9	9	9	9
9	1			1							11	11	11	11
10	1				1						12	12	12	12
11	1					1					13	13	13	13
	160	2	25	24	44	44	14	4	2	1	12.11	9	19	1,939

FIRST BROOD OF MOTHS.

Time of emergence.—The records of emergence of first-brood moths given in Table VIII cover observations with 786 individuals. The material used in this instance was secured from banded trees in orchards.

The first moth appeared June 9, while a maximum emergence occurred June 23, with irregularly decreasing numbers thereafter until July 22, when the last observation was made. The total emergence of 786 moths covered a period of 43 days.

FIG. 2.—Emergence curve of codling moths of the first brood, Roswell, N. Mex., 1912. (Original.)

A graphic description of the emergence of moths of the first brood appears in figure 2.

TABLE VIII.—*Time of emergence of codling moths of the first brood from larvæ collected systematically from banded trees and kept in cages, Roswell, N. Mex., 1912.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
June 9	1	July 1	28
11	6	2	34
12	7	3	33
13	15	4	29
14	15	5	15
15	7	6	14
16	26	7	11
17	21	8	11
18	2	9	19
19	20	10	11
20	32	11	12
21	16	12	17
22	35	13	11
23	86	14	10
24	55	15	8
25	9	16	1
26	29	17	9
27	30	18	9
28	28	19	1
29	24	22	1
30	32		

Total emergence, 786 moths.

Time of oviposition.—By reference to Table IX it will be found that the earliest deposition by moths of the first brood was made June 14, while the last oviposition occurred July 23. Hence the period of oviposition was approximately 40 days.

TABLE IX.—*Egg deposition by codling moths of first brood in stock jars at Roswell, N. Mex., 1912.*

Cage No.	Number of moths per cage.	Date of— Emergence of moth.	Date of— First oviposition.	Date of— Last oviposition.	Days— Before oviposition.	Days— Of oviposition.	Days— From time of emergence to last oviposition.
1	12	June 11	June 14	June 17	3	3	6
2	15	13	17	27	4	10	14
3	14	14	16	24	2	8	10
4	9	15	18	23	3	5	8
5	23	16	19	22	3	3	6
6	20	17	21	26	4	5	9
7	16	19	23	24	4	1	5
8	23	20	23	27	3	4	7
9	19	21	23	28	2	5	7
10	27	22	25	29	3	4	7
11	39	23	25	29	2	4	6
12	40	24	27	29	3	2	5
13	37	25	27	July 2	2	5	7
14	21	26	28	2	2	4	6
15	52	27	28	3	1	5	6
16	35	28	30	6	2	6	8
17	30	29	July 1	5	2	4	6
18	22	30	2	6	2	4	6
19	25	July 1	2	8	1	6	7
20	36	2	4	7	2	3	5
21	35	3	5	8	2	3	5
22	42	4	6	9	2	3	5
23	40	5	8	13	3	5	8
24	26	6	8	14	2	6	8
25	20	7	9	12	2	3	5
26	26	8	11	16	3	5	8
27	31	9	12	16	3	4	7
28	22	10	13	19	3	6	9
29	14	11	13	21	2	8	10
30	33	12	15	18	3	3	6
31	9	13	17	21	4	4	8
32	10	14	20	22	6	2	8
33	14	15	19	23	4	4	8
Average					2.7	4.45	7.15
Maximum					6	11	14
Minimum					1	2	5

The results given in Table IX show that on an average the first eggs were laid 2.7 days after the time of emergence of moths and that oviposition extended on an average to 4.45 days. The average length of time from the date of moth emergence to the last date of oviposition was 7.15 days; maximum, 14 days; minimum, 5 days.

Length of life of moths.—A summary of observations on the length of life of 367 male moths and 411 female moths is recorded in Table X. A study of this table will show that the longevity of the males was shorter than that for the females. On an average the males lived 4.44 days and females 6.24 days. The maximum length of life for the males was 16 days, and for the females 15 days.

TABLE X.—*Length of life of male and female codling moths of the first brood, Roswell, N. Mex., 1912.*

Summary of records of 778 individual moths.				Summary of records of 778 individual moths.			
Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
Days.		*Days.*		*Days.*		*Days.*	
1	2	1	0	10	1	10	18
2	25	2	10	11	1	11	7
3	72	3	25	12	0	12	2
4	99	4	44	13	0	13	1
5	98	5	82	14	0	14	1
6	48	6	87	15	0	15	2
7	10	7	57	16	1	16	0
8	8	8	48				
9	2	9	27		367		411

Average length of life of male moths, 4.44 days.
Average length of life of female moths, 6.24 days.
Maximum length of life of male moths, 16 days.
Maximum length of life of female moths, 15 days.
Minimum length of life of male moths, 1 day.
Minimum length of life of female moths, 2 days.

LENGTH OF LIFE CYCLE OF THE FIRST GENERATION.

Records of the observations on the life cycle of the first generation show that only 7 individuals completed the stages comprising the total life cycle of the insect. From this number an average of 51.14 days is found to represent the length of the period from date of deposition of eggs to emergence of moths of the same generation. The maximum period is 61 days; the minimum, 40 days. (See Table XI.)

TABLE XI.—*Length of life cycle of first generation of codling moth, Roswell, N. Mex., 1912.*

Date of egg deposition.	Number of individuals.	Moths emerged in specified days from time of deposition of eggs of the same generation.							Average days.	Minimum days.	Maximum days.	Total days.
		40	45	46	52	56	58	61				
April 26	1						1		58	58	58	58
May 10	1							1	61	61	61	61
11	2				1	1			54	52	56	108
20	2	1	1						42.5	40	45	85
27	1			1					46.	46	46	46
	7	1	1	1	1	1	1	1	51.14			358

A summary of results from observations on the separate stages of the first generation of the codling moth shows the total life cycle of the insect when computed by individual stages to compare very closely with the corresponding figures in Table XI. The length of life cycle by addition of separate stages is found to be 50.62 days as shown in Table XII, a difference of only 0.54 day.

TABLE XII.—*Summary of results from experiments on the separate stages of the first generation of the codling moth, Roswell, N. Mex., 1912.*

Complete life cycle of first generation.	Number of days.		
	Average.	Maximum.	Minimum.
Incubation of eggs	9.05	13	5
Feeding period of larvæ	21.52	27	15
Making of cocoons	5.24	12	2
Pupal stages	12.11	19	9
Time before egg deposition	2.7	6	1
Total	50.62	77	32

THE SECOND GENERATION.

THE SECOND BROOD OF EGGS.

Length of incubation.—Observations to determine the length of the period of incubation of eggs of the second brood were begun June 14 and continued until late in July. Eggs were deposited in large numbers during that period, and very accurate data regarding the length of the separate stages observed could be obtained. The average length of time from date of deposition to appearance of red ring was found to be 4.92 days; maximum, 4 days; minimum, 2 days. The average length of time from oviposition to appearance of the black spot was 4.26 days; maximum, 6 days; minimum, 3 days. For the period of time covering the duration of incubation an average of 5.62 days is determined; maximum, 8 days; minimum, 4 days. These records are found in Table XIII.

TABLE XIII.—*Length of incubation of second brood of eggs of the codling moth at Roswell, N. Mex., 1912.*

Observation No.	Number of eggs.	Date of—				Days for—		
		Oviposition.	Appearance of red ring.	Appearance of black spot.	Hatching.	Red ring.	Black spot.	Incubation.
1	8	June 14	June 16	June 20	June 21	2	6	7
2	68	16	20	22	23	4	6	7
3	17	16	20	22	24	4	6	8
4	56	17	20	22	23	3	5	6
5	40	17	20	23	24	3	6	7
6	15	18	20	23	24	2	5	6
7	7	18	20	23	25	2	5	7
8	5	19	22	24	25	3	5	6
9	2	19	22	24	26	3	5	7
10	3	20	23	24	25	3	4	5
11	18	21	24	25	27	3	4	6
12	70	22	25	27	28	3	5	6
13	52	23	26	27	28	3	4	5
14	27	23	26	28	29	3	5	6
15	42	24	27	28	29	2	3	5
16	31	24	27	28	30	3	4	6
17	24	25	28	29	30	3	4	5
18	24	25	28	29	July 1	3	4	6
19	29	26	28	30	1	2	4	5
20	12	26	28	30	2	2	4	6
21	80	27	29	July 1	2	2	4	5
22	43	27	29	1	3	2	4	6
23	100	28	July 1	2	3	3	4	5

TABLE XIII.—*Length of incubation of second brood of eggs of the codling moth at Roswell, N. Mex., 1912*—Continued.

Observation No.	Number of eggs.	Date of—				Days for—		
		Oviposition.	Appearance of red ring.	Appearance of black spot.	Hatching.	Red ring.	Black spot.	Incubation.
24	94	June 28	July 1	July 2	July 4	3	4	6
25	42	29	2	3	4	3	4	5
26	27	29	2	3	5	3	4	6
27	87	30	3	4	5	3	4	5
28	37	July 1	3	5	6	2	4	5
29	22	1	4	6	7	3	5	6
30	29	2	5	6	7	3	4	5
31	18	2	5	6	8	3	4	6
32	216	3	6	7	8	3	4	5
33	7	3	6	7	9	3	4	6
34	109	4	7	8	9	3	4	5
35	82	4	7	8	10	3	4	6
36	304	5	8	9	10	3	4	5
37	48	5	8	9	11	3	4	6
38	187	6	8	10	11	2	4	5
39	25	6	8	10	12	2	4	6
40	16	7	10	11	12	3	4	5
41	2	7	10	11	13	3	4	6
42	163	8	11	12	13	3	4	5
43	21	8	11	12	14	3	4	6
44	297	9	12	13	14	3	4	5
45	15	9	12	13	15	3	4	6
46	102	10	13	14	15	3	4	5
47	77	10	13	14	16	3	4	6
48	43	11	13	14	15	2	3	4
49	153	11	14	15	16	3	4	5
50	50	12	14	16	17	2	4	5
51	14	12	15	17	18	3	5	6
52	14	13	15	16	17	2	3	4
53	30	13	16	17	18	3	4	5
54	67	14	16	18	19	2	4	5
55	11	14	17	18	20	3	4	6
56	110	15	18	19	20	3	4	5
57	22	15	18	19	21	3	4	6
58	29	16	18	20	21	2	4	5
59	12	16	19	20	22	3	4	6
60	82	17	20	21	22	3	4	5
61	26	17	20	22	23	3	5	6
62	22	18	21	22	23	3	4	5
63	6	18	21	23	24	3	5	6
64	114	19	22	23	24	3	4	5
65	134	20	23	24	25	3	4	5
66	8	20	23	25	26	3	5	6
67	61	21	24	25	26	3	4	5
68	21	21	24	25	27	3	4	6
69	5	22	26	27	28	4	5	6
Average						4.92	4.26	5.62
Maximum						4	6	8
Minimum						2	3	4

Time of hatching.—The data in Table XIII, show that the first observation of hatching of eggs of the second brood occurred June 21, and continued quite regularly until July 28, thus covering a period of approximately five weeks.

THE SECOND BROOD OF LARVÆ.

Length of feeding period.—Records on the length of feeding period of 489 individual insects are brought together in Table XIV. This period covered a range of from 14 to 44 days, both transforming and wintering larvæ being included. The average length of feeding was found to be 21.23 days; maximum, 44 days; minimum, 14 days.

TABLE XIV.—*Length of feeding period of codling-moth larvæ of the second brood, Roswell, N. Mex., 1912.*

Date of hatching.	Number of individuals.	Length of feeding period in specified days, being the time from hatching of egg to leaving of fruit by larvæ.																										Average days.	Minimum days.	Maximum days.	Total days.
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	44				
June 23	25	....	1	3	3	8	1	4	2	....	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18.8	15	25	470
24	18	....	1	3	5	2	3	4	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17.83	15	20	321
25	8	....	....	2	1	1	....	1	....	2	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	19.25	16	23	154
26	2	....	....	1	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18	16	20	36
28	17	....	4	2	2	1	4	2	....	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	19.29	15	25	328
29	13	3	....	2	....	3	2	1	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17.61	14	22	229
30	10	....	1	3	1	1	1	1	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18	15	22	180
July 1	12	....	....	1	2	5	1	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18.41	16	22	221
2	9	....	....	....	2	1	1	....	1	2	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20.33	17	24	183
3	40	....	2	2	....	4	1	1	3	3	7	7	2	....	....	2	1	....	....	3	....	....	....	....	1	1	....	23.42	15	38	937
4	23	1	....	2	2	....	4	1	....	....	3	1	1	....	....	1	2	....	....	....	....	2	2	1	....	....	....	24.08	14	36	554
5	16	....	....	2	....	1	1	....	1	....	....	....	3	2	2	1	1	1	....	....	....	....	....	....	....	....	1	25.12	16	44	402
6	14	1	1	....	....	....	2	....	3	4	2	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20.57	14	24	288
7	25	2	....	....	2	6	5	4	4	....	3	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	19.75	17	24	494
8	18	....	1	....	....	5	4	1	3	....	....	2	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	20.55	15	31	370
9	25	....	....	....	7	2	3	2	....	2	1	1	....	....	....	....	2	1	1	1	1	....	....	....	1	....	....	22.56	17	37	564
10	24	....	1	3	3	2	3	1	2	3	1	1	2	....	....	....	....	....	....	....	1	....	....	1	....	....	....	20.87	15	36	501
11	28	....	1	1	2	....	3	1	1	....	....	....	12	1	1	1	....	....	....	1	1	1	1	....	....	....	....	24.21	15	35	678
12	24	....	1	....	....	4	1	5	....	....	5	1	....	2	....	3	2	....	....	....	....	....	....	....	....	....	....	22.45	15	29	539
13	26	....	....	....	3	3	1	3	4	3	2	1	1	4	1	....	....	....	....	....	....	....	....	....	....	....	....	21.53	17	27	560
14	24	....	....	....	....	2	4	2	9	1	1	....	....	....	....	1	....	1	3	....	....	....	....	....	....	....	....	22.37	18	31	537
15	7	....	....	....	2	....	....	1	....	1	....	....	....	....	1	....	....	....	....	....	....	....	....	1	1	....	....	25.14	17	37	176
16	21	....	....	1	....	1	8	1	2	2	2	....	....	....	2	2	....	....	....	....	....	....	....	....	....	....	....	21.33	16	28	448
17	14	....	....	....	2	4	....	2	....	....	....	2	3	....	....	....	....	....	1	....	....	....	....	....	....	....	....	21.42	17	31	300
18	7	2	....	1	2	....	....	....	1	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	18.14	14	28	127
19	10	....	....	3	....	1	....	....	3	....	1	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20.10	16	25	201
20	19	....	4	....	2	2	2	5	....	3	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18.89	15	25	359
21	10	....	....	2	....	2	....	....	....	....	....	....	4	....	....	1	1	....	....	....	....	....	....	....	....	....	....	22.50	16	29	225
	489	9	18	34	43	61	55	46	41	29	33	20	32	9	7	13	9	3	6	5	3	3	3	3	3	1	1	21.23	......	......	10,382

Length of feeding period of wintering larvæ.—The records on the length of feeding period of wintering larvæ of the second brood were separated from those of the transforming larvæ of the same generation, and by reference to Table XV results of observations with 211 individuals may be found. An average of 22.77 days is recorded for the entire number under observation as contrasted with an average of 21.23 days for both transforming and wintering larvæ of this generation.

The maximum period is 44 days; minimum, 15 days.

TABLE XV.—*Length of feeding of wintering second-brood larvæ of the codling moth, Roswell, N. Mex., 1912.*

Days of hatching.	Number of individuals.	Length of feeding period in specified days.																									Average days.	Maximum days.	Minimum days.	Total days.
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	44				
June 28	3		2	1																							16.3	17	16	49
30	1				1																						18.0	18	18	18
July 1	3						2		1																		21.0	22	20	42
2	2									1	1																23.5	24	23	47
3	16								2	1	4	1	1			1			4					1	1		27.9	38	22	446
4	7											1				1					2	2	1				32.6	36	25	228
5	10				1	1			1	1	1	2				1	1									1	25.9	44	18	259
6	14	1				2		2	5	3	1																21.3	24	15	298
7	11			2	3	1	1	1		2	1																19.8	24	17	218
8	9	1		1	2	2	1				1				1												19.8	28	15	178
9	6					1	1									1	1			1				1			28.0	37	19	168
10	12	1	2	1	1	2	1		1	1		1							1								20.2	32	15	242
11	13			1		1		1			4		1	1				1	1	1	1						25.8	34	17	336
12	18	1			3	1	6			3					2	2											21.7	29	15	391
13	12		1			1		2	3				4	1													22.8	27	16	274
14	17			1	1	3	1	6		1							1	3									22.6	31	17	384
15	3													1									1	1			33.3	37	27	100
16	14					6		2	1	1				2	2												22.2	28	19	311
17	7				2		1				1	2						1									23.0	31	18	161
18	2							1							1												24.5	28	21	49
19	9		1	1	1			2	1	1	1	1															20.8	25	16	187
20	13	1			4	1	3		3			1															19.7	25	15	257
21	9		1		2							4			1	1											23.2	29	16	209
Total	211	5	7	8	21	22	17	17	18	15	15	13	6	5	7	7	3	5	6	2	3	2	2	3	1	1	[1] 22.77	....	....	4,806

[1] Average.

Larval life in the cocoon.—The length of the period of time which the larvæ require to construct a cocoon preparatory to pupation or wintering, is found to vary considerably when large numbers of the larvæ are kept under observation. In Table XVI will be found the results of observations on 282 individual insects. Of this number 70 larvæ required 5 days, and an average period of 5.16 days is found to exist. The maximum time was 17 days; minimum, 1 day.

TABLE XVI.—*The making of cocoons of the second generation of the codling moth, Roswell, N. Mex., 1912.*

Date of leaving fruit.	Number of individuals.	Length of cocooning period in specified days.															Average days.	Minimum days.	Maximum days.	Total days.
		1	2	3	4	5	6	7	8	9	10	11	12	13	16	17				
July 8	1			1													3.0	3	3	3
9	4			1	2			1									4.5	3	7	18
10	6				4	2											4.3	4	5	26
11	12		2	3	2	1	4										4.2	2	6	50
12	5			1	3	1											4.0	3	5	20
13	12			1	8	1	1								1		5.2	3	16	62
14	7				2	1	3	1									5.4	4	7	38
15	5	1			1	1	1						1				5.6	1	12	28
16	5				2	2	1										4.8	4	6	24
17	11			1	2	2	3	2								1	6.4	3	17	70
18	12			1	1	3	3	2		2							6.0	3	9	72
19	12				3	5	2	2									5.3	4	7	63
20	6				1	5											4.8	4	5	29
21	13				4	3	4	1						1			5.8	4	13	75
22	2					2											5.0	5	5	10
23	8		2		5		1										3.7	2	6	30
24	7		1	1		2			3								5.6	2	8	39
25	24		1	1	1						1						4.8	2	10	19
26	21	2	2	3	4	2	7		1								4.3	1	8	91
27	21			4	1	8	3	3	1		1						5.4	3	10	113
28	8			1		3	2	1				1					6.0	3	11	48
29	6				1	1	3		1								5.8	4	8	35
30	8				2	3		2					1				6.1	4	12	49
31	7						1	5					1				7.6	6	12	53
Aug. 1	11		1	2	1	3	3	1									4.8	2	7	52
2	7		1		1	4		1									4.7	2	7	33
3	7			1	3	1	1	1									4.7	3	7	33
4	28		1	2	3	11	7	2	2								5.3	2	8	147
5	4				2	1	1										4.8	4	6	19
6	7		1		4	1			1								4.4	2	8	31
7	5		2	1	2												3.0	2	4	15
8	3						1		1	1							8.3	6	9	25
9	3				1		1	1									5.7	4	7	17
10	2				2												4.0	4	4	8
11	1							1									7.0	7	7	7
15	1					1											5.0	5	5	5
Total	282	3	14	25	68	70	53	27	10	3	2	1	3	1	1	1	5.16			1,457

THE SECOND BROOD OF PUPÆ.

Time of pupation.—Investigations show the earliest recorded pupation of individuals of this brood to have occurred July 14, and the latest on August 31. Actual pupations are thus shown to cover a period of 48 days. (See Table XVII.)

Length of pupal stage.—A record on the length of the pupal stage was established from observations with 211 individuals, and reveals the fact that the pupal period varied from 8 to 19 days. The average period was 11.23 days. These records are found in Table XVII.

TABLE XVII.—*Pupal stage of second brood codling moth, Roswell, N. Mex., 1912.*

Date of pupation.	Number of individuals.	Length of pupal period in days.												Average days.	Minimum days.	Maximum days.	Total days.
		8	9	10	11	12	13	14	15	16	17	18	19				
July 14	15			12	2	1								10.4	10	12	156
15	4		1		3									10.5	9	11	42
16	5			5										10	10	10	50
17	5		1	2	2									10.2	9	11	51
18	7				7									11	11	11	77
19	15		1	5	8					1				10.86	9	16	163
20	15			10	5									10.33	10	11	155
21	14			3	5	5	1							11.28	10	13	158
22	16		2	5	7	2								10.56	9	12	169
23	13			3	6	4								11.07	10	12	144
24	2					1	1							12.5	12	13	25
25	1				1									11	11	11	11
26	9			1	3	5								11.44	10	12	103
27	10			2	7		1							11	10	13	110
28	11			5	4	2								10.72	10	12	118
29	5			2				2					1	13.4	10	19	67
30	3	1	1				1							10	8	13	30
31	2				2									11	11	11	22
Aug. 1	14	1		6		6	1							10.92	8	13	153
2	3				2	1								11.33	11	12	34
3	8			5	1			2						11.12	10	14	89
4	3			1	2									10.66	10	11	32
5	1		1											9	9	9	9
9	11				10	1								11.09	11	12	122
10	2				2									11	11	11	22
13	2			1		1								11	10	12	22
14	2				2									11	11	11	22
16	3				2		1							11.66	11	13	35
17	1					1								12	12	12	12
19	2				1	1								11.5	11	12	23
20	1				1									11	11	11	11
25	2						1			1				14.5	13	16	29
26	1											1		18	18	18	18
27	2		1		1									10	9	11	20
31	1			1										10	10	10	10
Total	211	2	8	69	86	31	7	4		2		1	1	11.23			2,314

THE SECOND BROOD OF MOTHS.

Time of emergence.—The records on time of emergence of codling moths of the second generation may be found in Table XVIII. The earliest emergence of this brood occurred July 18, when nine moths emerged. Emergence continued more or less regularly until a maximum number of 242 was reached on August 7. The last emergence of which record was made occurred September 11.

TABLE XVIII.—*Time of emergence of codling moths of the second generation, Roswell, N. Mex., 1912.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 18	9	Aug. 16	114
19	11	17	70
20	23	18	55
21	10	19	66
22	44	20	36
23	58	21	33
24	68	22	40
25	100	23	44
26	93	24	29
27	47	25	22
28	91	26	17
29	145	27	32
30	121	28	16
31	72	29	16
Aug. 1	178	30	10
2	125	31	6
3	99	Sept. 1	6
4	199	2	9
5	181	4	7
6	216	5	4
7	242	6	1
8	179	7	2
9	109	8	1
10	194	10	1
11	152	11	1
12	167		
13	166		
14	55		
15	56	Total	3,848

Moths from band record larvæ.—In all, 5,320 larvæ of the second brood were collected systematically from banded trees in orchards and kept in cages in order that records might be obtained on emergence of moths from such sources. From the total larvæ secured in this way there emerged 3,848 moths, thus showing that 72.34 per cent of the larvæ under observation proved to be transforming larvæ. These records are shown in Table XIX.

TABLE XIX.—*Number of codling moths emerging from second-brood larvæ collected systematically from banded trees and kept in cages. Roswell, N. Mex., 1912.*

Date of collection.	Number of larvæ.	Number of moths.	Date of collection.	Number of larvæ.	Number of moths.
July 7	66	57	Aug. 6	235	159
10	179	162	9	261	131
13	303	249	12	232	73
16	451	372	15	142	28
19	410	368	18	110	20
22	609	530	21	88	12
25	678	596	24	86	2
28	623	483	27	88	1
31	399	354			
Aug. 3	360	251	Total	5,320	3,848

The rate and duration of the emergence of codling moths of this brood is described graphically in figure 3. As shown in Table XVIII, a maximum number emerged August 7, various fluctuations having occurred preceding that date and continuing throughout the period, The time of oviposition in orchards may be determined with fair precision from the combined data on the habits of the moths in captivity and from the results of the rearing experiments.

In conducting the experiments, the results of which are shown in Table XX, eggs of the codling moth were readily obtained by confining a number of moths together in cages. It is not possible by this method to determine the number of eggs thus produced, but the time and period of egg deposition can be ascertained.

FIG. 3.—Emergence curve of codling moths of the second brood, Roswell, N. Mex., 1912. (Original.)

The results show the average length of time from emergence of moths until first oviposition to be 2.2 days; maximum, 4 days; minimum, 2 days. The average length of the period for the duration of oviposition was 7.1 days; maximum, 12 days; minimum, 1 day. From time of emergence to last oviposition the average was 9.3 days; maximum, 14 days; minimum, 6 days.

TABLE XX.—*Egg deposition by codling moths of the second brood, Roswell, N. Mex., 1912.*

Cage No.	Number of moths per cage.	Date of— Emergence of moths.	Date of— First oviposition.	Date of— Last oviposition.	Days— Before oviposition.	Days— Of oviposition.	Days— From time of emergence to last oviposition.
1....	26	July 18	July 21	July 28	3	7	10
2....	14	19	23	24	4	1	5
3....	28	20	24	26	4	2	6
4....	26	21	24	29	3	5	8
5....	37	22	24	29	2	5	7
6....	35	23	26	Aug. 3	3	10	13
7....	36	24	26	4	2	9	11
8....	32	25	27	8	2	12	14
9....	40	26	28	2	2	5	7
10....	40	27	29	10	2	12	14
11....	43	28	30	6	2	7	9
12....	40	29	31	7	2	7	9
13....	47	30	Aug. 1	8	2	7	9
14....	40	31	2	12	2	10	12
15....	43	Aug. 1	3	9	2	6	8
16....	45	2	4	10	2	6	8
17....	47	3	5	14	2	9	11
18....	52	4	6	14	2	8	10
19....	33	5	7	11	2	4	6
20....	43	6	9	19	3	10	13
21....	40	7	9	14	2	5	7
22....	50	8	10	19	2	9	11
23....	40	9	11	23	2	12	14
24....	33	10	13	22	3	9	12
25....	34	11	13	24	2	11	13
26....	38	12	14	23	2	9	11
27....	25	13	15	23	2	8	10
28....	30	14	17	22	3	5	8
29....	30	15	17	24	2	7	9
30....	35	16	18	29	2	11	13
31....	35	17	19	25	2	6	8
32....	40	18	20	27	2	7	9
33....	37	19	21	27	2	6	8
34....	30	20	22	28	2	6	8
35....	33	21	23	28	2	5	7
36....	27	22	24	30	2	6	8
37....	43	23	25	Sept. 5	2	11	13
38....	27	24	26	4	2	9	11
39....	20	25	27	3	2	7	9
40....	17	26	28	3	2	6	8
41....	32	27	29	4	2	6	8
42....	17	28	30	4	2	5	7
43....	24	29	31	5	2	5	7
44....	10	31	Sept. 3	6	3	3	6
45....	16	Sept. 2	5	8	3	3	6
Average days					2.2	7.1	9.3
Maximum days					4	12	14
Minimum days					2	1	6

Length of life of moths.—Observations in this connection were made with a total of 1,416 moths confined in cages in order to secure mortality records. The results obtained with this number of individual moths give the average length of life of male moths to be 5.49 days; female moths, 7.58 days; maximum length of life of male moths, 12 days; female moths, 24 days; the minimum length of life of moths of both sexes is identical, 2 days. These records may be found in Table XXI.

TABLE XXI.—*Length of life of male and female codling moths of the second brood. Summary of records of 1,416 individual moths, Roswell, N. Mex., 1912.*

Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.
Days.		*Days.*	
2	3	2	4
3	54	3	11
4	132	4	38
5	165	5	69
6	151	6	147
7	90	7	163
8	40	8	118
9	9	9	66
10	8	10	53
11	3	11	33
12	4	12	25
13	0	13	7
14	0	14	8
15	0	15	8
16	0	16	4
17	0	17	2
24	0	24	1

Average length of life of male moths, 5.49 days; average length of life of female moths, 7.58 days; maximum length of life of male moths, 12 days; maximum length of life of female moths, 24 days; minimum length of life of male moths, 2 days; minimum length of life of female moths, 2 days.

LIFE CYCLE OF SECOND GENERATION.

In order to secure accurate data on the length of the life cycle of the codling moth of the second generation, observations were conducted by means of which the length of time from the date of egg deposition to emergence of moth could be determined. A total of 283 individual moths were used in this test, and the results show a range of variation in the life cycle from 32 to 68 days, with an average period of 41.26 days. These results are shown in Table XXII.

TABLE XXII.—*Length of life cycle of the second generation of the codling moth, Roswell, N. Mex., 1912.*

Date of egg deposition.	Number of individuals.	Moths emerged in specified days from time of deposition of eggs of the same generation.																								Average days.	Minimum days.	Maximum days.	Total days.
		32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	68				
June 16	21				1	3	1		6	1	2	1	2			1	2		1							40.6	35	49	853
17	18					1	3	2	2	2	3	2	1	1	1											40.0	36	45	720
18	6					2		1						1	1	1										40.8	36	46	245
19	1						1																			37.0	37	37	37
22	14				1			1	3		1	2	2	1		1	1		1							41.9	35	49	587
24	13			3				1	1	3	3		1		1											39.2	34	45	510
25	10		1		2			2	1	1		2		1												38.6	33	44	386
26	11						4	2	1			3	1													39.3	37	43	432
27	33						1	3	1	1	5	5	4	4		5		2	1	1						41.9	37	50	1,382
29	18		1		2		1	3	4	1		1	1	1	1		1		1							40.0	33	49	720
30	7								1			1			1			1	1		2					46.4	39	51	325
July 1	20		1					1	2	2		5	5	3		1										41.6	33	46	832
3	26					1		1	6	2	3	4		2	2	1			1			2		1		42.6	36	54	1,110
4	7			1					1		1	2			1										1	44.4	34	68	311
6	13			2				1			1		7			1	1									41.6	34	47	541
7	20						1	1			1	7	2	5		1	2									42.8	37	47	856
8	10								1	1		3	1			1		1	1				1			44.4	39	53	444
9	4							1				1	2													41.5	38	43	166
10	7						1	1		1	2					2										41.3	37	46	289
12	7					1		3		1	1			1												39.3	36	44	275
13	5	1						1	1	1														1		40.6	32	54	203
14	3					1	1							1												39.0	36	44	117
15	8			2		2	1	1				1	1													37.5	34	43	300
16	1					1																				36.0	36	36	36
	283	1	3	8	6	12	15	26	31	17	23	40	30	21	8	15	7	4	7	1	2	2	1	2	1	41.26	......	......	11,677

Accumulated records on the time of development of the codling moth in its stages of egg, larva, and pupa are summarized in Table XXIII. A sum composed of the average figures given under each of the several stages shows a total life cycle of 41.38 days. This sum is found to correspond very closely with the length of life cycle as given in Table XXII, there being a difference of but 0.12 day.

TABLE XXIII.—*Summary records on the time of development of the codling moth of the second generation in its stages of egg, larva, and pupa, Roswell, N. Mex., 1912.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Number of individuals.	Length of period of feeding larva.			Number of individuals.	Length of cocooning period.			Number of individuals.	Length of pupal stage.			Number of individuals.	Total length of life cycle.		
				Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.
June 16	21	147	21	18.8	15	25	21	4.04	3	7	21	10.7	8	19	21	40.6	35	49
17	18	126	18	17.8	15	20	18	4.8	4	7	18	10.3	8	13	18	40.0	36	45
18	6	42	6	19.3	16	23	6	3.6	2	5	6	10.8	10	12	6	40.8	36	46
19	1	7	1	16.0	16	16	1	5.0	5	5	1	9.0	9	9	1	37.0	37	37
22	14	84	14	18.5	15	25	14	5.3	2	17	14	10.5	7	14	14	41.9	35	49
24	13	65	13	16.1	14	22	13	5.7	1	16	13	10.9	5	17	13	39.2	34	45
25	10	50	10	18.1	15	22	10	4.4	3	6	10	11.1	9	16	10	38.6	33	44
26	11	55	11	18.1	16	22	11	5.1	4	7	11	11.1	9	15	11	39.3	37	43
27	33	190	33	20.7	15	25	33	5.2	1	10	33	11.4	7	22	33	41.9	37	50
29	18	90	18	19.7	14	29	18	4.4	2	7	18	10.8	8	13	18	40.0	33	49
30	7	35	7	24.0	16	28	7	7.7	5	13	7	9.7	5	13	7	46.4	39	51
July 1	20	117	20	19.5	14	23	20	5.3	3	10	20	11.1	9	14	20	41.6	33	46
3	26	147	26	21.0	17	32	26	5.8	2	12	26	10.3	8	15	26	42.6	36	54
4	7	42	7	21.1	16	36	7	5.14	2	11	7	12.1	10	21	7	44.4	34	68
6	13	65	13	21.3	15	25	13	4.3	2	6	13	11.0	8	16	13	41.6	34	47
7	20	114	20	21.5	17	28	20	5.9	3	7	20	10.3	3	13	20	42.8	37	47
8	10	60	10	21.3	18	28	10	5.5	3	8	10	11.3	10	13	10	44.4	39	53
9	4	24	4	19.0	17	22	4	5.5	4	7	4	11.0	9	12	4	41.5	38	43
10	7	42	7	19.6	16	23	7	4.9	2	6	7	10.8	10	14	7	41.3	37	46
12	7	35	7	19.0	17	24	7	4.3	2	8	7	11.1	10	13	7	39.3	36	44
13	5	25	5	15.6	14	17	5	4.6	3	7	5	14.8	10	26	5	40.6	32	54
14	3	14	3	17.7	16	21	3	6.7	5	9	3	10.0	10	10	3	39.0	36	44
15	8	40	8	16.5	15	20	8	5.8	4	8	8	10.1	9	11	8	37.5	34	43
16	1	5	1	16.0	16	16	1	4.0	4	4	1	11.0	11	11	1	36.0	36	36
	283	....	283	19.6	....	....	283	5.19	....	....	283	10.87	....	....	283	41.26	....	....

Total days incubation for all eggs, 1,621; average number of days incubation, 5.72.

THE THIRD GENERATION.

THE THIRD BROOD OF EGGS.

Length of incubation.—In Table XXIV will be found the results of 96 observations of eggs of the codling moth in an endeavor to determine the length of the several stages from time of deposition until hatching occurs. The average length of time from date of deposition to the appearance of the red ring was 3.22 days; maximum, 5 days; minimum, 2 days. The average time until the appearance of the black spot was 4.22 days; maximum, 6 days; minimum, 3 days. From date of deposition until time of hatching the average period was 5.75 days; maximum, 9 days; minimum, 4 days.

TABLE XXIV.—*Length of incubation of third brood of eggs of the codling moth at Roswell, N. Mex., 1912.*

Observation No.	Number of eggs.	Date of— Oviposition.	Date of— Appearance of red ring.	Date of— Appearance of black spot.	Date of— Hatching.	Days for— Red ring.	Days for— Black spot.	Days for— Incubation.
1	53	July 22	July 24	July 25	July 26	2	3	4
2	46	22	24	25	27	2	3	5
3	112	23	26	27	28	3	4	5
4	30	23	26	27	29	3	4	6
5	120	24	27	28	29	3	4	5
6	26	24	27	28	30	3	4	6
7	506	25	28	29	30	3	4	5
8	42	25	28	29	31	3	4	6
9	401	26	29	30	31	3	4	5
10	103	26	29	30	Aug. 1	3	4	6
11	342	27	30	31	1	3	4	5
12	127	27	20	31	2	3	4	6
13	192	28	31	Aug. 1	2	3	4	5
14	46	28	31	1	3	3	4	6
15	203	29	Aug. 1	2	3	3	4	5
16	151	29	1	2	4	3	4	6
17	341	30	2	3	4	3	4	5
18	85	30	2	3	5	3	4	6
19	432	31	3	4	5	3	4	5
20	70	31	3	4	6	3	4	6
21	(1)	Aug. 1	4	5	6	3	4	5
22	(1)	1	4	5	7	3	4	6
23	195	2	5	6	7	3	4	5
24	15	2	5	6	8	3	4	6
25	160	3	6	7	8	3	4	5
26	15	3	6	7	9	3	4	6
27	227	4	7	8	9	3	4	5
28	5	4	7	8	10	3	4	6
29	158	5	8	9	10	3	4	5
30	12	5	8	9	11	3	4	6
31	100	6	9	10	11	3	4	5
32	8	6	9	10	12	3	4	6
33	100	7	10	11	12	3	4	5
34	2	7	10	11	13	3	4	6
35	307	8	11	12	13	3	4	5
36	102	8	11	12	14	3	4	6
37	195	9	12	13	14	3	4	5
38	12	9	12	13	15	3	4	6
39	300	10	13	14	15	3	4	5
40	16	10	13	14	16	3	4	6
41	90	11	14	15	16	3	4	5
42	110	11	14	15	17	3	4	6
43	104	12	15	16	17	3	4	5
44	6	12	15	16	18	3	4	6
45	80	13	16	17	18	3	4	5
46	180	13	16	17	19	3	4	6
47	200	14	17	18	19	3	4	5
48	109	14	17	18	20	3	4	6
49	207	15	18	19	20	3	4	5
50	77	15	18	19	21	3	4	6
51	60	16	19	20	21	3	4	5
52	80	16	19	20	22	3	4	5
53	116	17	20	21	22	3	4	6
54	6	17	20	21	23	3	4	6

TABLE XXIV.—*Length of incubation of third brood of eggs of the codling moth at Roswell, N. Mex., 1912*—Continued.

Observation No.	Number of eggs.	Date of—				Days for—		
		Oviposition.	Appearance of red ring.	Appearance of black spots.	Hatching.	Red ring.	Black spot.	Incubation.
55	329	Aug. 18	Aug. 21	Aug. 22	Aug. 23	3	4	5
56	123	18	21	22	24	3	4	6
57	137	19	22	23	24	3	4	5
58	5	19	22	23	25	3	4	6
59	120	20	23	24	25	3	4	5
60	112	20	23	24	26	3	4	6
61	92	21	24	25	26	3	4	5
62	225	21	24	25	27	3	4	6
63	125	22	25	26	27	3	4	5
64	31	22	25	26	28	3	4	6
65	142	23	26	27	28	3	4	5
66	54	23	26	27	29	3	4	6
67	97	24	27	28	29	3	4	5
68	7	24	27	28	30	3	4	6
69	302	25	28	29	30	3	4	5
70	107	25	28	29	31	3	4	6
71	75	26	29	30	31	3	4	5
72	341	26	29	30	Sept. 1	3	4	6
73	7	27	30	31	1	3	4	5
74	160	27	30	31	2	3	4	6
75	24	28	Sept. 1	Sept. 2	3	4	5	6
76	8	28	1	2	4	4	5	7
77	52	29	2	3	4	4	5	6
78	16	29	2	3	5	4	5	7
79	90	30	3	4	5	4	5	6
80	6	30	3	4	6	4	5	7
81	4	31	4	5	6	4	5	6
82	8	31	4	5	7	4	5	7
83	162	Sept. 1	5	6	7	4	5	6
84	46	1	5	6	8	4	5	7
85	84	2	6	7	8	4	5	6
86	16	2	6	7	9	4	5	7
87	10	3	7	8	9	4	5	6
88	46	3	7	8	10	4	5	7
89	16	4	8	9	10	4	5	6
90	6	4	8	9	11	4	5	7
91	10	5	9	10	11	4	5	6
92	4	5	9	10	12	4	5	7
93	4	6	10	11	12	4	5	6
94	13[1]	7	11	12	14	4	5	7
95	20	8	13	14	16	5	6	8
96	7	8	13	14	17	5	6	9
Maximum						5	6	9
Minimum						2	3	4
Average						3.22	4.22	5.75

1 Exact number of eggs not recorded.

Time of hatching.—According to the records in Table XXIV hatching of eggs of this brood began July 26 and continued until after the middle of September. A study of the table will show that hatching in greatest numbers was found to occur between August 1 and August 8.

THE THIRD BROOD OF LARVÆ.

Length of feeding period.—A total of 829 individual insects were kept under observation in order to obtain the records found in Table XXV. During the progress of the experiments the transforming larvæ were not separated from the wintering larvæ, which possibly influences the average length of the feeding period to some extent. The records given cover a variation in the length of the feeding period of from 15 to 56 days, or a range of variation of 41 days. The average length of the period was 26.55 days.

TABLE XXV.—*Length of feeding period of third brood codling-moth larvæ, Roswell, N. Mex., 1912.*

Date of hatching.	Number of individuals.	Length of feeding period in specified days, being the time from hatching of egg to leaving of fruit by larvæ.																																					Average days.	Minimum days.	Maximum days.	Total days.
		15	16	17	18	19	20	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	47	48	49	50	51	52	56				
July 27	10				3		1		1	2		1	1		1																										25.1	18	28	251
July 28	16				3		3	5	3	1					1																										21.06	18	28	337
July 29	49				4			8	4	7	7	4	4		2	3	1	2											1	1	1										24.59	18	44	1,205
July 30	27							2	4	4	2	4	1	2			1	1	1			1		1		1			1				1								28.22	21	46	762
July 31	13					2		1	1	1	2	2				1	1	1						1																	25.15	19	37	327
Aug. 1	51			1		5	6	11	2	5	6			1	1	6	2	1		1	1		2																		24.01	17	36	1,225
Aug. 2	55				1	7	14	8	6	1		7	2		2	5				1						1															22.8	18	39	1,254
Aug. 3	42				2	4	5	5	2	11	1	3	1	2			1		1			1	3																		23.33	18	36	980
Aug. 4	72			1	3	6	9	23	1	3	4	3	6	3	1		2				2	1	1					1		1				2	1						24.34	17	48	1,753
Aug. 5	23		1	1	2	4	2	1		1	3	1	1		1		1	1		1		1																			21.17	16	34	487
Aug. 7	46		1	3	9	7	4	7	4	1	4	2	1		1					1		1																			21.04	16	35	968
Aug. 8	50	1	1	5	7	3	2	3	7	5	4	1	4	1	2	1	1			1				1																	22.06	15	37	1,103
Aug. 9	19				2		2	3	3	1	1			1	2			1	1	1			1																		23.1	18	36	439
Aug. 10	16				2	1	1	1	3	1		1		1	1	1				1		1		1																	24.93	18	37	399
Aug. 11	10				6				3							1																									20.3	18	29	203
Aug. 12	22				2	7		1	1	2		2			1	2	1	1		2																					23.68	18	33	521
Aug. 13	17									3	5	5						2	1				1																		26.17	23	36	445
Aug. 14	17		1	1	4	1		4	1	1		1			1	1			1																						21.53	16	32	367
Aug. 15	10					2	2		1	2	1	1	1																												21.6	19	26	210
Aug. 16	16				3	1	1				1	3		2		1					1	2		1																	25.37	18	37	406
Aug. 17	23				2	1	3		2	6		1	2	2	2				1		1																				23.04	18	34	530
Aug. 18	10				1	1	2	2	1	2			1																												21.3	18	26	213
Aug. 19	14				1	1	3				2		1	1			2		2		1																				27.28	18	34	382
Aug. 20	14							3	1	1	1			1	1				1		2	1	1		1																28.28	21	38	396
Aug. 21	9						3	2	1		1			1	1																										22.55	20	28	203
Aug. 22	4									1	2	1																													24.0	23	25	96
Aug. 23	8				3		2	1					1	1																											21.0	18	27	168
Aug. 24	15						2	3	1			1	3		1	2		1		1																					25.2	20	33	378
Aug. 25	12						1	1	1		1	4				1		2		1																					26.25	20	33	315
Aug. 26	15						2	1	2	3	2					3		2																							24.86	20	31	373
Aug. 27	16				1			1		6		1		1		1	1		3		1																				26.75	18	34	428
Aug. 28	3						1		1					1																											23.0	20	27	69
Aug. 29	11					1		1	1			1			3	3			1																						26.36	19	32	290
Aug. 30	3									1	1			1																											24.33	23	27	74
Aug. 31	8						1		1	2		1	2			1																									24.25	20	29	194
Sept. 1	4					1							1				1	1																							26.50	19	31	106
Sept. 2	15		1		1		2	1	1		1	1		1	1			1	1	2	1																				34.6	16	34	369
Sept. 3	9			1							1				1	1				1	1										1			1				1			34.11	17	51	307
Sept. 4	8												1		1		2	1		1										1		1									32.25	26	45	266

TABLE XXV.—*Length of feeding period of third brood codling-moth larvæ, Roswell, N. Mex., 1912*—Continued.

Date of hatching.	Number of individuals.	Length of feeding period in specified days, being the time from hatching of egg to leaving of fruit by larvæ.																																						Average days.	Minimum days.	Maximum days.	Total days.
		15	16	17	18	19	20	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	47	48	49	50	51	52	56				
Sept. 7	14												1	1	1	1	1			1	1				1		2			2					2					1	37.14	26	56	520
8	11													1		1	1	2			1					2								1		1	1				36.9	27	50	406
9	7								1		1					1	1						1		1							1						1			33.86	22	51	237
10	7																							1	1	1	1					1			1				1		42.71	37	52	299
11	3																						1			1				1											39.33	36	43	118
14	2							1															1																		28.5	21	36	57
16	3										1															1											1				37.66	24	50	113
	829	1	5	13	62	55	74	100	61	64	55	52	35	25	29	37	20	20	14	16	13	8	12	6	2	7	3	1	2	6	2	3	1	4	4	1	2	2	1	1	26.55	......	......	20,549

Larval observations with reference to the length of the cocooning period of this generation were limited to 26 individuals. Of this total the greatest number, 6, completed the construction of the cocoon in 4 days. The average length of this period was 6.48 days as compared with 5.24 days for the first brood and 5.16 days for the corresponding stage of the second generation. The records for the cocooning period for the third generation are found in Table XXVI.

TABLE XXVI.—*The making of cocoons of the third brood of the codling moth, Roswell, N. Mex., 1912.*

Date of leaving fruit.	Number of individuals.	Length of cocooning period in specified days.											Average days.	Minimum days.	Maximum days.	Total days.
		2	3	4	5	6	7	8	9	11	12	14				
Aug. 19	2	....	1	1	....	....	....	....	....	....	....	....	3.5	3	4	7
21	1	....	1	....	....	....	....	....	....	....	....	....	3.0	3	3	3
22	1	....	....	1	....	....	....	....	....	....	....	....	4.0	4	4	4
23	1	....	....	1	....	....	....	....	....	....	....	....	4.0	4	4	4
25	2	1	....	1	....	....	....	....	....	....	....	....	3.0	2	4	6
Sept. 1	2	....	....	....	1	....	....	1	....	....	....	....	6.5	5	8	13
2	2	....	....	....	....	1	1	....	....	....	....	....	6.5	6	7	13
3	2	....	....	1	....	....	....	....	1	....	....	....	6.5	4	9	13
4	1	....	....	....	....	....	....	....	1	....	....	....	9.0	9	9	9
5	2	....	....	....	1	....	....	1	....	....	....	....	6.5	5	8	13
6	3	....	....	....	....	....	1	1	....	....	1	....	9.0	7	12	27
7	3	....	....	....	....	....	....	1	1	1	....	....	9.3	8	11	28
8	1	....	....	1	....	....	....	....	....	....	....	....	4.0	4	4	4
9	1	....	....	....	....	....	....	....	....	....	....	1	14.0	14	14	14
10	2	....	....	....	1	....	....	....	....	....	1	....	8.5	5	12	17
	26	1	2	6	3	1	2	4	3	1	2	1	6.48	......	......	175

THE THIRD BROOD OF PUPÆ.

Time of pupation.—Observations on pupation in the rearing cages extended from August 19 until September 10, and experiments in this instance were conducted with only 17 individual insects. The small number available is due to the fact that large numbers of the larvæ of this brood proved to be wintering larvæ. Of those observed the greatest number having a specific period completed the pupal stage in 13 days. The average time for the entire number under observation was 14.94 days; maximum, 20 days; minimum, 11 days. The detailed results are shown in Table XXVII.

TABLE XXVII.—*Pupal stage of the third brood of the codling moth, Roswell, N. Mex., 1912.*

Date of pupation.	Number of individuals.	Length of pupal period in specified days, being the time from pupation to emergence of moth.								Average days.	Minimum days.	Maximum days.	Total days.
		11	12	13	14	15	17	19	20				
Aug. 19	1								1	20	20	20	20
23	1	1								11	11	11	11
Sept. 1	1	1								11	11	11	11
2	1		1							12	12	12	12
3	2			1		1				14	13	15	28
4	1					1				15	15	15	15
5	2				2					14	14	14	28
6	2			2						13	13	13	26
7	3			1				1	1	17.33	13	20	52
8	1					1				15	15	15	15
9	1							1		19	19	19	19
10	1						1			17	17	17	17
Total	17	2	1	4	2	3	1	2	2	14.94			254

THE THIRD BROOD OF MOTHS.

Time of emergence.—The limited number of moths with which the observations found in Table XXVIII were made is in proportion to the decreasing number of transforming larvæ as the season progressed. Emergence began September 3, and continued until September 28, thus covering a period of 25 days.

TABLE XXVIII.—*Time of emergence of moths of the third brood, Roswell, N. Mex., 1912.*

Date of emergence.	Number of moths.
Sept. 3	1
4	1
8	1
12	1
14	1
16	1
18	2
19	5
20	1
23	1
26	1
27	2
28	1
Total	19

LIFE CYCLE OF THIRD GENERATION.

While the number of individual insects under observation to determine the length of life cycle of the third generation is notably smaller than in previous corresponding cases a sufficient number were observed to determine the length of the period very satisfactorily. The range of variation was found to be from 36 to 62 days, the greatest number, 3, having 48 days An average of 48.57 days is indicated for the third brood, as compared with 41.26 days for the corresponding period of the second brood, and 51.14 days for the first brood. (See Table XXIX.)

TABLE XXIX.—*Length of life cycle of the third generation of the codling moth, Roswell, N. Mex., 1912.*

Date of egg deposition.	Number of individuals.	Moths emerged in specified days from time of deposition of eggs of the same generation.																Average days.	Minimum days.	Maximum. days.	Total days.
		36	40	41	44	45	46	47	48	49	50	51	52	54	55	60	62				
July 24	2			1			1											43.5	41	46	87
28	2								1								1	55.0	48	62	110
29	4					1				1			1			1		51.5	45	60	206
30	3	1									1	1						45.7	36	51	137
Aug. 2	3								2						1			50.3	48	55	151
3	1							1										47.0	47	47	47
4	2							1						1				50.5	47	54	101
9	1		1															40.0	40	40	40
10	1				1													44.0	44	44	44
	19	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	48.57	......	......	923

In Table XXX is brought together a condensed summary of records dealing with the codling moth of the third generation, showing the average length of the separate periods composing the life cycle of the insect. The average of the averages secured from the several stages recorded gives a total of 47.62. This sum when contrasted with the results as given in Table XXIX, shows a difference of but 0.95 days.

TABLE XXX.—*Summary records on the time of development of the codling moth of the third generation in its stages of egg, larva, and pupa, Roswell, N. Mex., 1912.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Number of individuals.	Length of feeding larvæ.			Number of individuals.	Length of cocooning period.			Number of individuals.	Length of pupal stage.			Number of individuals.	Total length of life cycle.		
				Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.
July 23	2	10	2	19.5	18	21	2	4.0	4	4	....	......	....	....	....	......	....	....
24	3	15	3	19.0	18	21	2	3.5	3	4	2	15.5	11	20	2	43.5	41	46
26	2	12	2	18.5	17	20	2	3.5	3	4	....	......	....	....	....	......	....	....
27	2	12	2	25.0	25	25	2	5.5	5	6	....	......	....	....	....	......	....	....
28	3	18	3	24.0	23	26	3	11.0	7	14	2	15.5	12	19	2	55.0	48	62
29	4	24	4	21.3	20	23	4	10.0	8	12	4	14.3	11	20	4	51.5	45	60
30	3	18	3	22.0	16	26	1	8.0	8	8	1	13.0	13	13	3	45.6	36	51
Aug. 2	5	25	5	21.2	16	25	5	6.2	2	9	3	16.0	14	19	3	51.5	48	55
3	1	5	1	20.0	20	20	1	8.0	8	8	1	14.0	14	14	1	47.0	47	47
4	3	15	3	23.0	21	27	3	6.7	5	8	2	15.0	13	17	2	50.5	47	54
9	1	5	1	16.0	16	16	1	4.0	4	4	1	15.0	15	15	1	40.0	40	40
10	1	5	1	20.0	20	20	1	4.0	4	4	1	15.0	15	15	1	44.0	44	44
	30	164	30	21.23	....	....	27	6.7	....	....	17	14.9	....	....	19	47.61	....	....

Average length of incubation period in days, 5.46.

SEASONAL HISTORY OF THE CODLING MOTH DURING 1912.

In figure 4 a summary is given in graphical form to illustrate the progress of the development of the codling moth in the course of the entire season of 1912. The shaded portions are arranged to represent the periods in which the insect was prevalent in greatest numbers as determined by the average length of the several stages. The V-shaped characters appearing before the shaded portions show the time at which it was possible for the stage to begin, while the dotted lines following the shaded areas represent a possible continuation of any particular stage as shown by observations which may, in many instances, represent extreme conditions.

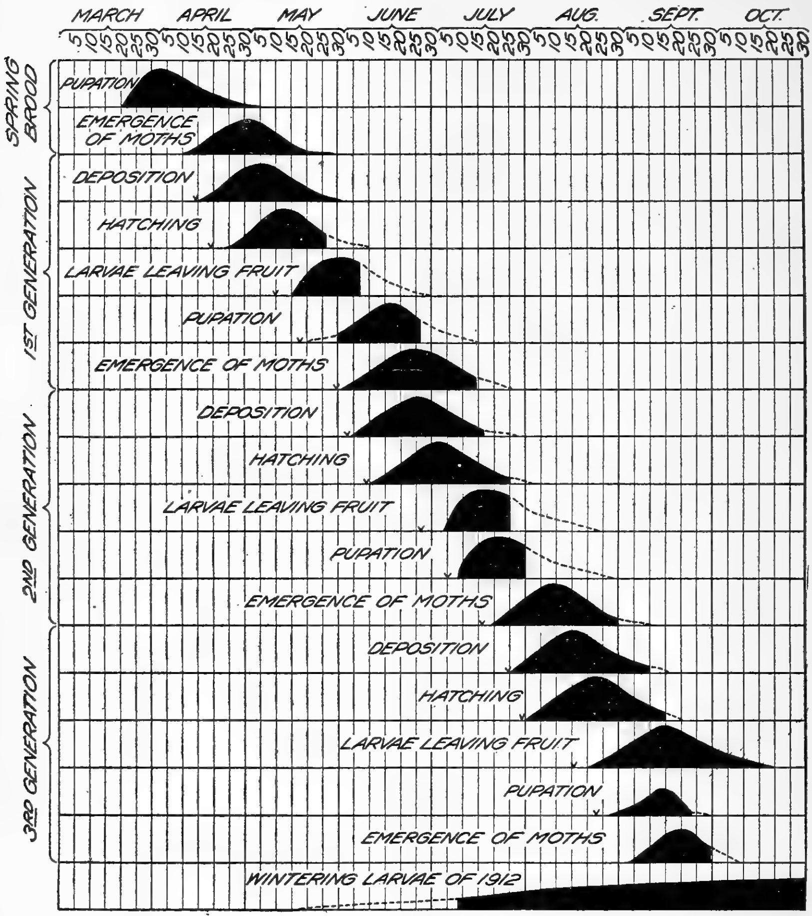

FIG. 4.—Diagram of the seasonal history of the codling moth for 1912, Roswell, N. Mex. (Original.)

BAND-RECORD LARVÆ OF 1912.

Throughout the season careful record was kept of larvæ collected from banded trees in orchards, and the results of these observations appear in Table XXXI.

Collections from field material began as early in the season as May 26, and continued regularly every three days throughout the season. In this way a total of 9,400 larvæ were collected, of which number 6,922 transformed and emerged as moths. Of the 6,922 moths which comprise the total emergence for both seasons, 4,636 moths appeared during the season of 1912, and 2,286 moths emerged from overwintering larvæ in the spring of 1913. Of all the larvæ collected throughout the season of 1912, moths from the transforming larvæ composed 49.32 per cent, almost one-half of the entire number. Moths emerging from wintering larvæ comprised 24.32 per cent of the total number, while 26.36 per cent of the larvæ died without transforming.

TABLE XXXI.—*Band records for the codling moth for the season of 1912, Roswell, N. Mex. Emergence records completed, 1913.*

Collection No.	Date of collecting.	Number of larvæ collected.	Number of moths emerged, 1912.	Number of moths emerged, 1913.	Total number moths, 1912–13.	Number of dead.	Per cent of dead.
1	May 26	16	5	....	5	11	68.7
2	29	59	44	....	44	15	25.4
3	June 1	89	63	....	63	26	29.2
4	4	88	77	....	77	11	12.5
5	7	171	167	1	168	3	1.75
6	10	88	88	....	88	....	0
7	13	72	66	1	67	5	6.94
8	16	90	73	....	73	17	18.88
9	19	62	57	....	57	5	8.06
10	22	33	27	1	28	5	15.1
11	25	37	34	....	34	3	8.1
12	28	45	41	....	41	4	9.75
13	July 1	32	25	....	25	7	21.87
14	4	39	22	....	22	17	43.6
15	7	66	57	1	58	8	12.1
16	10	179	162	....	162	17	9.5
17	13	303	248	....	248	55	18.1
18	16	451	372	....	372	79	17.5
19	19	411	368	....	368	43	10.46
20	22	609	530	1	531	78	12.8
21	25	678	596	7	603	75	11.06
22	28	623	483	8	491	132	21.18
23	31	399	354	9	363	36	9.02
24	Aug. 3	360	251	23	274	86	23.9
25	6	235	159	35	194	41	17.4
26	9	261	131	53	184	77	29.5
27	12	232	73	86	159	73	31.46
28	15	142	28	74	102	40	28.17
29	18	110	20	59	79	31	28.18
30	21	88	12	49	61	27	30.68
31	24	86	2	55	57	29	33.72
32	27	88	1	51	52	36	40.9
33	30	106	....	54	54	52	49.05
34	Sept. 2	133	....	79	79	54	40.6
35	5	127	....	84	84	43	33.8
36	8	179	....	90	90	89	49.7
37	11	207	....	122	122	85	41.06
38	14	306	....	175	175	131	42.8
39	17	239	....	133	133	106	45.19
40	20	283	....	144	144	139	49.1
41	23	201	....	135	135	66	32.8
42	26	212	....	111	111	101	47.64
43	29	242	....	106	106	136	56.2
44	Oct. 2	112	....	59	59	53	47.3
45	5	180	....	88	88	92	51.1
46	8	149	....	99	99	50	33.55
47	11	149	....	72	72	77	51.7
48	14	67	....	52	52	15	22.18
49	17	61	....	45	45	16	26.2
50	20	104	....	61	61	43	41.34
51	23	35	....	18	18	17	48.56
52	26	39	....	23	23	16	41.02
53	29	24	....	19	19	5	20.83
54	Nov. 1	3	....	3	3	0	0
		9,400	4,636	2,286	6,922	2,478	....

	Per cent.
Moths from transforming larvæ composed	49.32
Moths from wintering larvæ composed	24.32
Dead larvæ composed	26.36
Total	100.00

The occurrence of the larvæ of the codling moth in orchards as shown by results of the band records is graphically described by means of curves in figure 5. From this figure it may be deduced that the greatest number of larvæ of the first brood leaving the fruit was found to occur about June 7. Larvæ of the second brood appeared under the bands in greatest numbers in the neighborhood of July 25, or practically 50 days after a maximum was found in the first brood. With reference to the third brood it will be noted that the greatest number of larvæ were found September 14, which is just 51 days following the corresponding stage of the second generation. These figures agree very well, however, with the conclusion

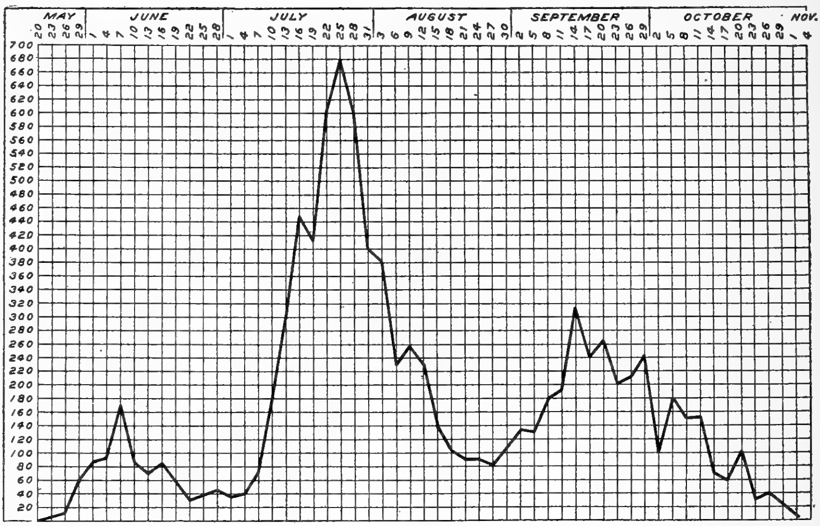

FIG. 5.—Curve showing occurrence of the codling-moth larvæ under bands on apple trees, Roswell, N. Mex., 1912. (Original.)

drawn from records obtained in the rearing shelter with insects in confinement. (See summary tables on the different generations.)

SEASONAL-HISTORY STUDIES OF 1913.

The results of the 1913 life-history studies of the codling moth do not, in general, differ greatly from those obtained the previous year. They are, however, somewhat more complete and detailed in certain respects, and are therefore more satisfactory, for the observations during this season were conducted under more favorable conditions.

SOURCE OF REARING MATERIAL.

Rearing material consisted of wintering larvæ of 1912, kept in an outside shelter and subjected to existing weather conditions, and other material which could be considered quite normal and from which reliable conclusions could be drawn.

The larvæ were from both band-record material and the results of propagation of the several broods in the rearing shelter.

Many of the larvæ had been kept over winter in pieces of decayed wood and in strips of corrugated paper. These formed a suitable means of seclusion for the wintering larvæ and were kept in glass jars with easily removable tops, from which the emerging moths could be taken without difficulty.

METHOD OF PROCEDURE.

Immediately following emergence the moths were transferred to large glass receptacles covered with white cheesecloth or muslin, and there allowed to proceed with mating and egg deposition. Fresh pear foliage was placed within these receptacles daily, and while the majority of the eggs were deposited on the leaves and stems, frequently the sides of the jar would be quite thickly studded with eggs when the number of females per jar was excessive.

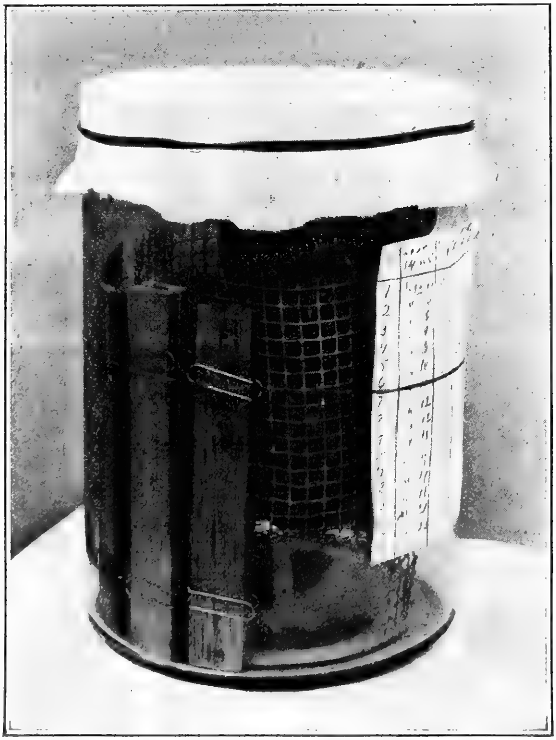

FIG. 6.—Sample cage used to determine feeding period of codling-moth larvæ. (Hammar.)

The leaves and the twigs upon which the eggs had been deposited were removed from the containers daily and placed in a glass jar in which a holder or basket made from woven wire of fine mesh, and containing a number of medium-size apples, had been inserted. Only unsprayed fruit was used for this purpose, and care was exercised to make certain that no fruit was used that had been previously entered by larvæ. When the period of incubation was over the leaves and the twigs were removed, because the presence of the leaves frequently offered a place for cocooning and pupation, which was not desirable. In figure 6 a sample cage is illustrated, and the strips of wood which were prepared and dropped in to provide acceptable hiding places during cocooning and pupation are also shown.

In order that observations might be made during the period of cocooning and at the time of pupation without disturbing the specimens in their normal manner of procedure, small strips of wood with slight partitions between them were used, held together by paper clips bent at a convenient angle. Over the partitions was pasted a thin film of mica with a sprinkling of fine sawdust underneath. This device, described in previous publications of the bureau, proved to suffice throughout the period of experimentation.

Figure 7 is an illustration of the strips of wood used.

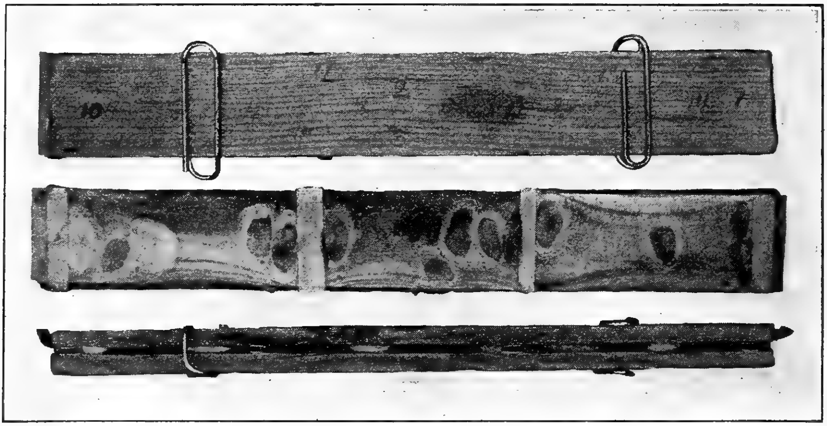

Fig. 7.—Device used to obtain pupal records of the codling moth. (Hammar.)

THE SPRING BROOD.

SPRING BROOD OF PUPÆ.

Time of pupation.—The first record of pupation of overwintering larvæ took place March 23, and from that date pupation continued more or less regularly for a period of 51 days, the last pupation recorded occurring on May 13.

Length of pupal stage.—The length of the pupal period of the spring brood has a range of from 12 to 36 days, the majority of the individuals, however, completing the stage after 26 days had elapsed. The average for the entire time is found to be 22.97 days. (See Table XXXII.)

TABLE XXXII.—*Pupal period of the spring brood of the codling moth, Roswell, N. Mex., 1913.*

Date of pupation.	Number of individuals.	Length of pupal period in specified days.																							Average days.	Maximum days.	Minimum days.	Total days.
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	33	34	36				
Mar. 23	4															2	2								26.5	27	26	106
24	6															4					1		1		28.3	34	26	170
25	7														1	3	1	1		1					27.0	31	25	189
26	7													1	2				1		1	1		1	29.3	36	24	205
27	3											1	1							1					25.3	31	22	76
28	12										1	8	1	1	1										22.4	25	21	269
29	23										5	6	4	8											22.7	24	21	521
30	20									1		2	14			2			1						23.4	30	20	468
31	17									2	1	3			5	6									24.0	26	20	408
Apr. 1	19						1	2	1	1	6			2	2	2		2							22.3	28	17	424
2	29						1	1		2			1	9	5	8	2								24.2	27	17	701
3	18			1		1	1	2	1			1	3			4	3	1							22.6	28	14	406
4	5				1			1					1			1	1								21.8	27	15	109
5	7										1		2		1	2				1					25.0	31	21	175
6	2								1					1											21.5	24	19	43
7	5		1										3		1										21.4	25	13	107
8	7	2							1				2	1	1										19.7	25	12	138
9	3		1						1				1												18.3	23	13	55
10	1															1									26.0	26	26	26
11	2	2																							12.0	12	12	24
12	2		1										1												18.0	23	13	36
13	1				1																				15.0	15	15	15
14	2					1				1															18.0	20	16	36
16	3	1									2														18.0	21	12	54
17	1										1														21.0	21	21	21
18	1								1																19.0	19	19	19
19	3	1							1		1														17.3	21	12	52
20	1							1																	18.0	18	18	18
27	1								1																19.0	19	19	19
30	1					1																			16.0	16	16	16
May 8	1								1																19.0	19	19	19
13	1				1																				15.0	15	15	15
	215	6	3	1	3	3	3	7	9	7	18	21	34	23	19	35	9	4	2	3	2	1	1	1	22.97	......	......	4,940

SPRING BROOD OF MOTHS.

Time of emergence.—The emergence of moths of the spring brood was found to begin as early as April 7 and to continue more or less regularly until the first part of June. However, a maximum emergence was found to occur in the 10-day period between April 17 and 27, in which a total of 1,334 moths emerged. The emergence during this period represents 58.33 per cent of the entire number which emerged during 1913, covering a period of 57 days. Further examination of Table XXXIII will show that of 7,343 larvæ, the entire number collected, a sum total of 5,216 moths emerged, being equivalent to 71.04 per cent of the larvæ It may be noted in this connection that 56.19 per cent of the moths emerged during 1912, while 43.81 per cent emerged in the spring of 1913.

TABLE XXXIII.—*Time of emergence of codling moths of the spring brood, Roswell, N. Mex., 1913. Larvæ from band-record material of 1912.*

Date of collection.	Number of larvæ.	Number of moths, 1912.	April.																					
			7	8	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
June 7	171	77																						
June 13	27	167												1										
June 22	33	27											1											
July 4	39	22																						
July 22	609	530												1										
July 25	678	596									2				1					2		1		
July 28	623	483												2	3				1				1	
July 31	399	354													5						1	1		1
Aug. 3	360	251										4	2	2	2	4				5		1	1	2
Aug. 6	235	159									2	2	4		2	5			3	5	3	2	2	
Aug. 9	261	131									2	7	6	8	2	5		2	1	9	2	3		1
Aug. 12	231	71							2	1	5	15	10	7	1	11	1	2	3	6	11	1	3	2
Aug. 15	142	28							1		3	10	10	5	4	11			1	8	10	1	2	
Aug. 18	110	20							1	3	5	10	10	9	1	4			1	5		1	3	2
Aug. 21	88	12								3	7	7	7	2	2	10				3	4		2	1
Aug. 24	86	2									1	1	3			7			2	6	4	3	4	3
Aug. 27	83	1									1	4	3			5			1	4	3	3	5	2
Aug. 30	106										3	4	3	2	1	5			6	3	4	2	2	4
Sept. 2	133										1	3	6	1	8	7			4	7	4	2	3	4
Sept. 5	127									2		2	4	5	1	9				8	4	5	1	4
Sept. 8	179											1	3	2	1	13	1		3	10	2	10	6	8
Sept. 11	207									1	1	4	9	2	1	11	1		6	10	12	8	7	3
Sept. 14	316							1		1	5	8	14	6	5	19	3		3	14	15	5	3	10
Sept. 17	239											2	4	4		10		1	2	16	8	4	8	10
Sept. 20	283								2	3	3	12	11	2	2	19	2		7	13	6	7	3	9
Sept. 23	201								2	1	5	16	15	6	5	19		1	6	15	10	4	8	3
Sept. 26	212								1	4	4	14	15	5	1	16	2		3	18	5	4	4	2
Sept. 29	242								1	1	3	7	10	5	2	10	1		4	14	4	12	5	5
Oct. 2	112							1	1	2	3	6	6	2		9			3	5	4	2	7	5
Oct. 5	180				3		4	3	15	16	12	12	9	1		5				4	1		2	
Oct. 8	149		2	1	3	5	5	5	14	18	11	11	9	3		5			3	2				1
Oct. 11	149								1	4	7	10	13	6	3	6				4		5		3
Oct. 14	67						3	2	6	9	11	8	5	2		2			1	2		1		
Oct. 17	61						1	1	1	6	10	6	3	1	1	6				1	1	1	1	2
Oct. 20	104						1	2	7	9	11	13	6	1	1	5			1	1		1		1
Oct. 23	35									1	2	2	1		1	1			2	3	1		3	
Oct. 26	39							1	1	1	2	2	1	1	1	6			1	1	2	1		2
Oct. 29	24							2	2	4	1	2	2			2			1	1		1	1	
Nov. 1	3						1				1									1				
Total....	7,343	2,931	2	1	6	5	15	18	58	90	124	204	205	94	57	247	11	6	69	206	121	92	87	90

Date of collection.	May.																														June.	Number of moths, 1913.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	3	
June 7										1																						1
June 13																																1
June 22																																1
July 4									1																							1
July 22																																1
July 25	1																															7
July 28		1																														8
July 31					1																											9
Aug. 3																																23
Aug. 6	1			1	1	1				1																						35
Aug. 9	1		2	1				1																								53
Aug. 12		2			1	1													1													86
Aug. 15	1	2	1		1					1											1						1					74
Aug. 18	2								1																				1			59
Aug. 21		1																														49
Aug. 24	4				2	1				2	1		1			3		2	1	3							1					55
Aug. 27	2	2	1	1			1			2							1	2	3	1	1	1				2						51
Aug. 30	1	3		1	2	2						1								1	1	1		1	1							54
Sept. 2	1	3			3		3			3	1	1	2		1	1	1	3		2	2			1				1				99
Sept. 5	3	5		2	6	2	1	1	1	1	1	1	1	3			1	2		2				1	1			1	2		1	84
Sept. 8	5	3	1		1	2	1		3		3		1	1	1	1	1	2				2					2					90
Sept. 11	6	2	2		2	1	1	4	2		1	2				2	3	3	2	3	4	1	3				1			1		122
Sept. 14	3	8		2		4	2	5	1				2	2	1	2	4	6	4	3	2	1	1	2	2	3	1			1		174
Sept. 17	8	9		2	1	2	5	3	2			1	2		1	1		5	1	1	2	2	3	2	1	3						133
Sept. 20	4	3	3	1		2	4	2	2	1	1	1					2	3	4	4		1	1		1	2	1					144
Sept. 23	3	1		2		1		2		2		1	1		1			1		1	1			1		1						135
Sept. 26	1	3	1	2	3		1										1		1													111
Sept. 29	8	4	1		3				1	1		1							1		1					1						106
Oct. 2	2																					1		1								59
Oct. 5		1																														88
Oct. 8																				1												99
Oct. 11	2	1	1	1	1								1					1	1				1									72
Oct. 14																																52
Oct. 17																		1			1								1			45
Oct. 20	1																															61
Oct. 23													1																			18
Oct. 26																																23
Oct. 29																																19
Nov. 1																																3
Total....	60	54	13	16	27	20	19	18	14	15	8	9	12	6	5	10	20	31	19	22	16	10	9	9	6	12	7	2	4	2	1	2,285

The time and rate of emergence of the spring brood of moths are illustrated diagrammatically in figure 8.

Egg deposition.—The records on egg deposition by individual moths of the spring brood are somewhat limited, because of the 34 females isolated in this connection only 9 gave results worthy of record, as shown in Table XXXIV.

From a total deposition of 257 eggs it will be noted that the maximum deposition per female was 91 eggs, while the average number per moth was approximately 28 eggs. On an average 7.33 days

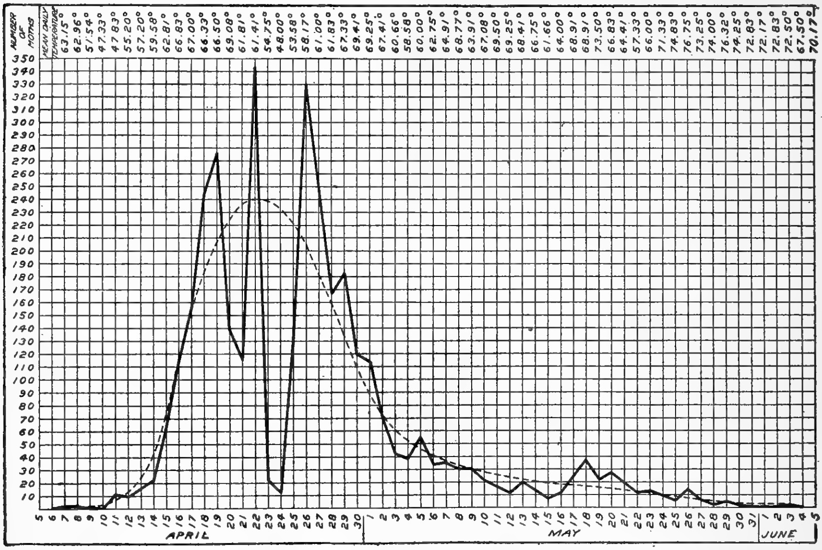

FIG. 8.—Curve showing emergence of codling moths of the spring brood, Roswell, N. Mex., 1913. (Original.)

elapsed from time of emergence to first oviposition. The maximum time, however, was 12 days; the minimum, 3 days. The length of the period of oviposition for the 9 individuals under observation averaged 5.55 days; the maximum was 10 days; minimum, 1 day. On an average the moths in confinement lived 12.88 days, which is somewhat longer than the corresponding period for the female moths of the spring brood of 1912, which gave an average length of life of 8.47 days. In 1912 the maximum length of life of female moths of the spring brood was 22 days; in 1913 the corresponding period was 20 days.

TABLE XXXIV.—*Egg deposition by individual codling moths of the spring brood, Roswell, N. Mex., 1913.*

Observation No.	Date of emergence of moths.	Date of oviposition and number of eggs deposited.																					Death of moth.	Total number of eggs per moth.	Length of period before first oviposition.	Period from first to last oviposition.	Period from emergence to last oviposition.	Total length of life of moth.
			May.																									
			2	3	4	6	7	8	9	10	12	13	14	15	18	22	24	25	26	27	29	30						
																									Days.	*Days.*	*Days.*	*Days.*
1	April 28						1			10		9	3	4									May 18	27	9	9	17	20
2	28				2	1		19	2	3	2	3											15	32	6	10	15	17
3	28									2		3	5										15	10	12	5	16	17
4	28									11	6	20											14	37	12	4	15	16
5	28	17																					2	17	3	1	3	4
6	28		1	1		3		12															8	17	4	7	10	10
7	May 9														10	7							22	17	9	5	13	13
8	20																26	37	3	10	15		29	91	4	5	9	9
9	20																			1	7	1	30	9	7	4	10	10
Total		17	1	1	2	4	1	31	2	26	8	35	8	4	10	7	26	37	3	11	22	1		257				

Summary.	Average.	Maximum.	Minimum.
Number of days from emergence of moth to first oviposition	7.33	12	3
Number of eggs deposited by each female	28.5	91	9
Length of oviposition period in days	5.55	10	1
Number of days from emergence of moth to last oviposition	12.0	17	3
Length of life of moth in days	12.88	20	4

NOTE.—In this instance 34 individual moths were isolated of which only 9 gave results worthy of record. Moths confined in jelly glasses with pear foliage. Fresh moistened foliage placed in jar daily. Moths confined in numbers in large jars 2 days prior to isolation to insure mating.

THE FIRST GENERATION.

FIRST BROOD OF EGGS.

Time of deposition.—The earliest deposition of eggs of the first brood in rearing cages occurred April 16, and more or less regular depositions continued for a period of 45 days. The time for the occurrence of a maximum deposition, however, would appear to be near the latter part of the period, and the irregularities previously noticeable are probably due to weather conditions.

Length of incubation.—A total of 212 observations made in this connection show a range of variation in the length of the incubation period of 4 to 11 days. A decrease in the length of the period was somewhat noticeable as the season advanced, although exceptions occur. An average period of 5.96 days is found for the entire number. These results are shown in Table XXXV.

TABLE XXXV.—*Time of incubation of eggs and length of feeding period of larvæ of the first generation of the codling moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Length of feeding period of larva in specified days.																Average days.	Minimum days.	Maximum days.	Total days.
			16	19	20	21	22	23	24	25	26	27	28	29	30	31	32	38				
Apr. 16	4	11												1	1		1	1	32.2	29	38	129
19	1	10											1						28.0	28	28	28
28	2	7						1	1										23.5	23	24	47
29	12	7				1		2	2	1	4	1	1						24.9	21	28	299
May 1	12	8			2	3	1	2			2	2							23.08	20	27	277
2	2	8			1				1										22.0	20	24	44
3	9	7			1		1	2	2	2	1								23.5	20	26	212
5	1	6									1								26.0	26	26	26
7	3	6		1		1	1												20.7	19	26	62
8	7	6		1	2			2	2										21.8	19	24	153
9	3	6					2		1										22.7	22	24	68
10	5	5					2	1	1				1						23.8	22	28	119
11	6	5				1	1					1	2			1			26.1	21	31	157
12	7	5								2		2			2	1			27.8	25	31	195
13	16	5		1	1		3			1	3	4		3					25.1	19	29	403
14	8	5							2		2	3				1			26.5	24	31	212
19	8	5								2	3	1				1	1		27.2	25	32	218
21	7	6					1		1	2	2			1					25.3	22	29	177
23	2	4						1					1						25.2	23	28	51
24	7	4					3		1	1	1	1							24.0	22	27	168
25	10	4				1	1	2	1	2	1	2							24.3	21	27	243
26	12	5				1	2	2	3	2		1	1						24.0	21	28	288
27	7	5		1			2	1	3										22.29	19	24	156
28	20	5				1	1	1	9	3	5								24.4	21	26	487
29	15	6			2	1	2	2	4	1	1	2							23.4	20	27	352
30	13	5		1			5	3	2		1	1							23.0	19	27	299
31	13	5	1			1	1	5	2		1		1	1					23.5	16	29	305
	212	....	1	5	9	11	29	27	38	19	28	21	8	6	3	4	2	1	24.45	....	....	5,175

Total days' incubation for all eggs, 1,194; average incubation period, 5.96 days.

THE FIRST BROOD OF LARVÆ.

Length of feeding period.—The length of the feeding period of larvæ of this brood covered a range of 22 days, the greatest number, 38, having completed the period in 24 days. The maximum time is 38 days, and the minimum period 16 days. The average period for the entire 212 individuals is found to be 24.45 days, which is 2.93 days greater than the corresponding period for the first brood in 1912.

Feeding period of wintering larvæ.—It is generally conceded that wintering larvæ experience a longer feeding period than those transforming the same season. In Table XXXVI it is shown that of 15 wintering larvæ of the first brood a maximum period of 31 days was noted; a minimum period of 22 days, with an average period of 25.13 days. This is an increase of but 0.68 day over the feeding period of the transforming larvæ of this brood.

TABLE XXXVI.—*Length of feeding period of wintering codling-moth larvæ of the first brood, Roswell, N. Mex., 1913.*

Observation No.	Date of—		
	Hatching.	Leaving the fruit.	Days feeding.
1	May 9	June 5	27
2	9	5	27
3	15	6	22
4	16	12	27
5	16	16	31
6	18	14	27
7	27	19	23
8	28	21	24
9	28	22	25
10	28	23	26
11	28	24	27
12	29	20	22
13	June 2	26	24
14	4	27	23
15	4	July 1	27

Maximum days, 31; minimum days, 22; average, 25.13; average for transforming, 24.45.

Percentage of wintering larvæ.—Of the larvæ of the first brood under observation 15 of the 212 proved to be wintering larvæ, while 197 transformed the same season, showing as a result that only 7.16 per cent of the larvæ of this brood proved to be wintering larvæ.

Larval life in the cocoon.—The larval life in the cocoon is here broadly considered to be the time necessary for the making of the cocoons, and is recorded as the time elapsing between the date the larvæ leave the fruit and the time of pupation. The wintering larvæ of the first brood are not included here, since these remain in the larval stage until the following spring. In Table XXXVII are found the results of 193 observations which show a variation of from 2 to 21 days, and an average period of 5.7 days.

TABLE XXXVII.—*The making of cocoons of the first brood of the codling moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.															Average days.	Minimum days.	Maximum days.	Total days.
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	21				
Apr. 16	4					1		1		1		1					9.0	6	12	36
28	1				1												5.0	5	5	5
29	12			6	4	2											4.6	4	6	56
May 1	10		4	2	3	1											4.1	3	6	41
2	2	1		1													3.0	2	4	6
3	9		1	2	3	3											4.8	3	6	44
5	1						1										7.0	7	7	7
7	3		1	2													3.6	3	4	11
8	7		1	2			2	1			1						6.2	3	11	44
9	2			1		1											5.0	4	6	10
10	5			1		3	1										5.8	4	7	29
11	4				1	2	1										6.0	5	7	24
12	6								1	1		2		1	1		12.0	9	15	72
13	14				1	3	3			1	1		3	1		1	9.09	5	21	139
14	8			1		2	3	1			1						7.0	4	11	56
19	8	1	1		1	3	1	1									5.3	2	8	43
21	7			1	5	1											5.0	4	6	35
23	1			1													4.0	4	4	4
24	3				2	1											5.3	5	6	16
25	8		1	3	1			1					1	1			6.9	3	14	55
26	13		2	8	3												4.1	3	5	53
27	7	1		5	1												3.8	2	5	27
28	19			10	7		1								1		5.1	4	15	97
29	15		2	6	5	2											4.4	3	6	67
30	11			10	1												4.1	4	5	45
31	13			2	8		1	2									5.5	4	8	71
	193	3	13	64	47	25	14	7	1	3	3	3	4	3	2	1	5.7	....	....	1,093

THE FIRST BROOD OF PUPÆ.

Length of pupal period.—To determine the length of time occupied from the date of pupation until the emergence of moths, 148 individual insects were kept under observation. Of this number 36 moths emerged in 11 days, while the range of the pupal period was 16 days. The average time for the entire 148 pupæ was 11.76 days; maximum, 21 days; minimum, 5 days. These results are shown in Table XXXVIII.

TABLE XXXVIII.—*Pupal period of the first brood of the codling moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of pupal stage in specified days.															Average days.	Minimum days.	Maximum days.	Total days.
		5	6	7	8	9	10	11	12	13	14	15	16	17	19	21				
Apr. 16	2										1		1				15.0	14	16	30
29	12							1		2	4	5					14.0	11	15	168
May 1	8									1	4	3					14.3	13	15	114
2	2											2					15.0	15	15	30
3	6									2	2	2					14.0	13	15	84
7	2										1	1					14.5	14	15	29
8	6							1	2		1	1				1	14.1	11	21	85
9	2										2						14.0	14	14	28
10	3							1	1	1							12.0	11	13	36
11	2									2							13.0	13	13	26
12	6	1	1	3								1					7.8	5	15	47
13	5						1			1				2	1		15.2	10	19	76
14	8						2	3	1	1					1		12.1	10	19	97
19	6				1	3	1	1									9.3	8	11	56
21	4						2	2									10.5	10	11	42
23	1							1									11.0	11	11	11
24	2			1		1											8.0	7	8	16
25	6					1	2	3									10.3	9	11	62
26	12				1		5	4	1				1				10.8	8	16	130
27	5					1	2		1				1				11.4	9	16	57
28	16					1	8	6	1								10.4	9	12	167
29	14				1		5	7			1						10.6	8	14	149
30	10					3		3	2		1		1				11.4	9	16	114
31	8						4	3	1								10.6	10	12	85
	148	1	1	4	3	10	32	36	10	10	17	15	4	2	2	1	11.76	....	....	1,739

THE FIRST BROOD OF MOTHS.

Time of emergence.—The records on the emergence of moths of the first brood are found in Table XXXIX, showing that from a total of 2,588 larvæ collected from banded trees between May 20 and June 22 there emerged 2,219 moths. Thus 85.75 per cent of the larvæ collected in this way proved to be transforming larvæ of the same season. Actual emergence covered a period extending from June 3 until July 10, while the greatest number of moths emerging on any specified day appeared on June 15, when 261 individuals emerged. A maximum emergence occurred in the four-day period from June 15 to June 19, when there emerged 882 moths, which constituted practically 40 per cent of the entire emergence covering a period of 37 days.

TABLE XXXIX.—*Time of emergence of codling moths of the first brood from larvæ collected from banded trees and kept in cages, Roswell, N. Mex., 1913.*

Date of collection.	Number of larvæ.	June—																											July—										Number of moths.
		3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	
May 20	5	1	...	...	1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3
23	40	...	4	17	6	3	4	...	3	...	1	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	39
26	140	...	...	4	26	11	27	13	28	14	3	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	129
29	833	...	...	...	...	...	...	...	2	13	27	77	259	133	77	34	20	6	4	2	1	1	2	1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	661
June 1	517	...	...	...	...	...	...	...	...	1	...	1	1	22	57	94	178	63	20	21	2	1	2	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	464
4	320	...	...	...	...	...	...	...	...	...	...	...	...	3	1	...	1	11	34	76	87	43	9	3	3	...	2	...	...	...	...	...	...	...	...	...	...	...	273
7	249	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	102	83	25	7	4	1	...	...	...	...	...	...	...	...	...	...	...	220
10	130	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	53	36	17	2	1	...	...	...	...	...	...	...	...	...	...	113
13	89	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	38	26	3	4	4	...	...	...	...	...	...	...	...	82
16	76	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	9	31	21	3	3	...	...	...	...	...	...	70
19	95	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	2	14	23	28	5	2	1	1	...	...	77
22	94	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	...	7	20	32	24	1	1	1	88
Total	2,588	1	4	21	33	14	31	13	33	28	31	80	261	159	135	128	199	80	58	99	99	147	100	82	53	59	34	15	37	41	26	38	26	34	25	2	1	1	2,219

The emergence of moths of the first generation is shown in the diagram appearing as figure 9. The larvæ used in these experiments were collected regularly from May 20 until June 22 from banded trees, and the curve in this figure represents the sum total of daily emergence from these larvæ.

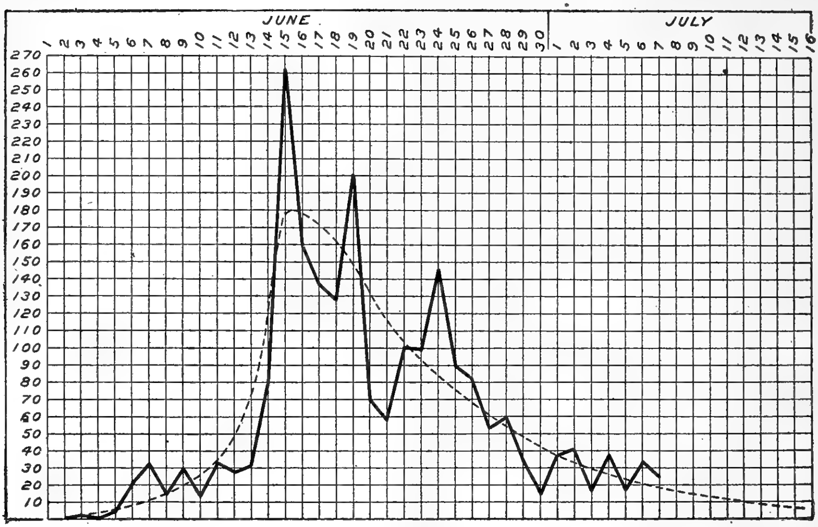

FIG. 9.—Curve showing emergence of codling moths of first brood, Roswell, N. Mex., 1913. (Original.)

LIFE CYCLE OF FIRST GENERATION.

The entire length of time required for the first generation of the codling moth to pass through the several stages and reach the adult stage is totaled in Table XL.

TABLE XL.—*Length of life cycle of first generation of codling moths from time of egg deposition to emergence of moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Moths emerged in specified days from time of deposition of eggs of the same generation.																			Average days.	Minimum days.	Maximum days.	Total days.
		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	56	60	65				
Apr. 16	2																			2	65.0	65	65	130
29	12						1			2		1	1	2		2	3				50.6	54	44	607
May 1	8								3		1		2	2							48.5	51	46	388
2	3							1						1		1					49.6	53	45	149
3	5							1					2	2							49.4	53	45	247
7	3					1			1	1											45.3	47	43	136
8	6					1		1				1	2	1							48.0	51	43	288
9	2										2										48.0	48	48	96
10	3									2		1									47.7	49	47	143
11	2							1						1							48.0	51	45	96
12	6													1	2		1	1	1		54.1	60	51	325
13	5									1			1		1	1	1				51.2	54	47	256
14	8								1			1	2	2	1			1			50.6	56	46	405
19	6							1	3			1	1								47.0	50	45	282
21	4								1	1	1			1							48.0	51	46	192
23	1									1											47.0	47	47	47
24	2	1	1																		39.5	40	39	79
25	6					4							2								45.3	50	43	272
26	12		1	1	3	1		3	2		1										43.9	48	40	525
27	5	1	1	1		1	1														41.4	44	39	207
28	16					3	5	5	2	1											44.3	47	43	710
29	14		2		1	1	3	2	2	1	2										44.2	48	40	622
30	10		2		2	2	2	1		1											43.0	47	40	430
31	8		2			2	1				1	1	1								44.6	50	40	357
	149	2	9	2	6	16	13	16	15	11	8	6	14	13	4	4	5	2	1	2	46.91			6,990

Of 149 individual insects under observation, 16 were found to have a total life cycle of 45 days. Two insects required 65 days and represent a maximum time for the brood; two specimens were found to have completed the previous stages in 39 days, which is considered the minimum time. An average time of 46.91 days prevails, and a range of variation of 26 days is noted.

EGG DEPOSITION BY INDIVIDUAL MOTHS.

Mating.—Records of egg deposition by individual females in captivity have proven of especial interest in connection with these studies of the codling moth. Records on egg laying and mating of the codling moth have been very limited, and statements by earlier investigators have been largely speculative estimates. The lack of information is due to the difficulty of getting moths to deposit eggs in a state of captivity, especially when the individual insects are isolated. Although many thousand moths have been under observation it has been only in rare instances that moths have been found in copula. In 1913 these observations were made for the first brood of moths, and in Table XLI these observations are listed under numbers 21, 23, and 48. The moths in connection with observation No. 21, both male and female, emerged June 22 and were found mating at 10 a. m. on June 24. Eggs were deposited the same day. The individuals in connection with observation No. 23, both male and female, emerged June 24 and mated on June 27 at 8 a. m. Eggs were deposited during the following night. The moths referred to as observation No. 48, male and female, emerged July 6 and were found in copula on July 7 at 9 a. m. and remained so until 2 p. m. of the same day. The wings of this female were not fully expanded, and this may account for the long mating, the moth when dead still having the abdomen distended with eggs. Since the moths are very inactive during the heat of the day it is very probable that mating takes place at twilight, during warm nights, and in the morning. Mating also very likely takes place under natural conditions shortly after the moths take flight after emergence, and as the sexes encounter each other.

Egg deposition.—In the course of these investigations it was noted that eggs were deposited in abundance when moths were confined together in numbers in large jars. This fact led to further experimentation and male and female moths were isolated, being removed from the larger jars after two days' confinement, and placed in smaller jars for observation of egg deposition. The moths were first fed on diluted sugar water placed on a small piece of sponge, but this method invariably made the jars sticky and in consequence the moths died prematurely. Later dried pear leaves were placed in each jar, each leaf being daily moistened with pure water. The dried leaves, being black, showed the presence of the white eggs; the most of the eggs, however, were placed on the side of the glass jars.

In all, 141 female moths were taken from the larger jars and isolated, some of these being accompanied by males and others being without males. Of these, 48 furnished oviposition records, as stated in Table XLI, while 93 of them, or two-thirds of the number, failed. Of the latter a few eggs resulted, though as far as observed they were all nonfertilized, one or two being deposited a day, though the greater number of the moths did not oviposit at all.

The confining of the moths in this manner results in a very abnormal condition for the insect, and markedly different results may occur normally in orchards. For instance, it was found that most of the moths died before all the eggs had been deposited, the dead females often containing an abundance of fully developed eggs. Thus the averages here obtained are unquestionably far below what normally occurs in the field. It is also likely that in many cases egg laying was delayed. The results, however, show what is possible in this connection and what might happen even under conditions considerably removed from the normal with reference to the extent of egg deposition and length of life of moths.

On an average the first eggs were deposited three days after the emergence of the moths, while a maximum length of time of 6 days and a minimum time of 2 days prevailed. The greatest number of eggs produced by a single female was 200, and the results averaged 80.2 eggs for the 48 females under observation. The moth listed under observation No. 8, in Table XLI, escaped before the test was concluded and might have deposited more eggs, as the abdomen was still quite distended with eggs. A total of 192 eggs were found in the jar.

As there exists a considerable degree of variation in the size of moths also, there probably is to be found variation in the number of eggs laid by each female. Moths of the spring brood are, as a whole, smaller than moths of the first and second broods, and probably are less productive than the latter.

In general the moths began ovipositing 3 days after emergence, although the shortest period was 2 days. The number of eggs deposited per female per day varied from 1 to 96 and averaged 20 eggs per day for the 48 moths. Normally this number would be greater. In confinement moths often ceased ovipositing for a day during the period of deposition, and frequently only one egg was deposited during 24 hours, although previously and later numerous depositions were made. On an average, oviposition extended over 5.7 days, and the moths died on an average 2 days after final oviposition, although sometimes death occurred the same day. In 1912, deposition records obtained with moths of the first brood show that the average extent of the deposition period was 4.45 days. The average length of time from the date of emergence to that of the last oviposition was almost identical for the corresponding broods of the two seasons, there being a difference of but 0.55 day.

TABLE XLI.—*Egg deposition by individual codling moths of the first brood, Roswell, N. Mex., 1913.*

Moth No.	Date of emergence of moths.	June 18	June 19	June 20	June 21	June 22	June 23	June 24	June 25	June 26	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5	July 6	July 7	July 8	July 9	July 10	July 11	July 12	July 13	Death of moth.	Total number of eggs per moth.	Length of period before first oviposition.	Period from first to last ovipositions.	Period from emergence to last oviposition.	Life of moth after last oviposition.	Total length of life of moth.	Number of days on which ovipositions occurred.	Average number eggs per oviposition per female.
																														Days.	Days.	Days.	Days.	Days.		
1	June 13	8	6	8	12	15	19	5																				June 26	73	5	7	11	2	13	7	10.4
2	15		6			1		10		4	5	1	7	3														July 1	37	4	12	15	1	16	8	4.6
3	17				1	5	3	4		2	1	3		8														4	27	4	10	13	4	17	8	3.4
4	17		1	20	14	2	8																					June 26	45	2	5	6	3	9	5	9.0
5	17		10	44	1	28																						24	83	2	4	5	2	7	4	20.75
6	17		22	60		11																						25	93	2	4	5	3	8	3	31.0
7	17		22		2	2	1			1																		30	28	2	8	9	4	6	5	5.6
8	17		21	50	30	2	12	29	25	23																			192	2	8	9			8	24.0
9	17					5	26	5	2	15	23																	July 2	76	5	6	10	5	15	6	12.6
10	20								5	26																		June 30	31	5	2	6	4	10	2	15.5
11	20							61	16	1																		27	78	4	3	6	1	7	3	26.0
12	20							27	23	28	30	29	15	10	11													July 3	173	4	8	11	2	13	8	21.6
13	20							51	18																			June 27	69	4	2	5	2	7	2	34.5
14	22								23	19																		27	42	3	2	4	1	5	2	21.0
15	22									1	22	2																29	25	4	3	6	1	7	3	8.3
16	22							3	23	47	1	41	6	5	5	3												July 7	134	2	9	10	5	15	9	14.8
17[1]	22							27			47	2	2																78	2	6	7			4	19.5
18	22									1	24		2	15	10													2	52	4	6	9	1	10	5	10.4
19	22							65	3	42	32	34	6	18														2	200	2	7	8	2	10	7	28.5
20	22							62	18	4																		6	84	2	3	4	10	14	2	28.0
21	22							23	31	7	30		1	12														3	112	2	7	8	3	11	6	18.7
22	22							42	4	37	2	9	4	2	3													3	103	2	8	9	2	11	8	12.8
23	24										6																	June 30	6	3	1	3	3	6	1	6.0
24[1]	24											96																	96	4	1	4			1	96.0
25	24										51	12																July 5	63	3	2	4	7	11	2	31.5
26	24										20	3	49	14	41	35		18										6	180	3	8	10	2	12	7	25.7
27	24										1	1	6	15	2	11	3	22										6	61	3	8	10	2	12	8	7.6
28	24											14	26	25	2	5	28	2										6	102	4	7	10	2	12	7	14.5
29	24											3	5				10	1		39								10	58	4	9	12	4	16	5	11.6
30	24											1	1		7		1	18	5	30	18							9	81	4	10	13	2	15	8	10.1
31	27															3	2	19	7	1				1				11	33	5	9	13	1	14	6	5.5
32	27												1			1			5		1	5	8	4	4			11	29	2	13	14		14	8	3.6
33	27												37	40	15	25												4	117	2	4	5	2	7	4	29.25
34[1]	28														5	26		8											39	3	4	6			3	13.0
35	28													35	22	30	30	33	4									7	154	2	6	7	2	9	6	25.66
36	28													10	2	34												5	46	2	3	4	3	7	3	15.3
37	29														63	25	19	36	11	2								9	156	2	6	7	3	10	6	26.0

38	29																	1		3	5	3	10	4	13	14	13	53	6	9	14		14	8	6.6
39	29														32	37	1	40	22	18							7	150	2	6	7	1	8	6	25.0
40	30															29	7	2	52								7	90	2	4	5	2	7	4	22.5
41	30															43	44	3	42								7	132	2	4	5	2	7	4	33.0
42	30															7	1	2		7	1						9	19	2	6	7	2	9	5	3.8
43	30																40	10	21	20	48	2					10	141	3	6	8	2	10	6	23.5
44	30																16	13	28	10							7	67	3	4	6	1	7	4	16.75
45	30															31	13	3	2								7	49	2	4	5	2	7	4	12.25
46	30															63											5	63	2	1	2	3	5	1	63.0
47	30																		27	45	44						9	116	5	3	7	2	9	3	38.66
48	July 6																					1	9	1		2	1	14	14	2	6	7	1	8	5	2.8
Total		8	88	182	60	71	69	414	199	258	295	251	168	212	220	408	215	231	227	172	115	13	20	16	8	15	15		3,950							

[1] Moth escaped before record was completed.

SUMMARY.

	Average.	Maximum.	Minimum.
Number of days from emergence of moth to first oviposition	3.02	6	2
Number of eggs deposited by each female	80.2	200	6
Number of eggs deposited per day per female	19.805	96	1
Length of oviposition period in days	5.7	13	1
Number of days of actual oviposition	5.02	9	1
Number of days from emergence of moth to last oviposition	7.7	15	2
Number of days moth lived after last oviposition	2.47	10	1
Length of life of moth in days	10.3	17	5

SUMMARY OF RECORDS.

A condensed summary of the records on the stages of the first generation is found in Table XLII. The average of the averages of the different stages is found to be 47.37 days, as compared with 46.91 days in the total life cycle column, a difference of but .46 day. The length of the life cycle of the insect of the first generation of 1912, as obtained by addition of the separate stages, was shown to be 50.62 days. This number is 3.25 days greater than the corresponding sum of the length of the several stages of the first generation during 1913.

TABLE XLII.—*Summary of records on the time of development of the codling moth of the first generation in its stages of egg, larva, and pupa, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Number of individuals.	Length of feeding larva.			Number of individuals.	Length of cocooning period.			Number of individuals.	Length of pupal stage.			Number of individuals.	Total length of life cycle.		
				Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.
Apr. 16	4	11	4	32.2	29	38	4	9.0	6	12	2	15.0	14	16	2	65.0	65	65
19	1	10	1	28.0	28	28												
28	2	7	2	23.5	23	24	1	5.0	5	5								
29	12	7	12	24.9	21	28	12	4.6	4	6	12	14.0	11	15	12	50.6	55	44
May 1	12	8	12	23.1	20	27	10	4.1	3	6	8	14.3	13	15	8	48.5	51	46
2	2	8	2	22.0	20	24	2	3.0	2	4	2	15.0	15	15	3	49.6	53	45
3	9	7	9	23.5	20	26	9	4.8	3	6	6	14.0	13	15	5	49.4	53	45
5	1	6	1	26.0	26	26	1	7.0	7	7								
7	3	6	3	20.7	19	26	3	3.6	3	4	2	14.5	14	15	3	45.3	47	43
8	7	6	7	21.8	19	24	7	6.2	3	11	6	14.1	11	21	6	48.0	51	43
9	3	6	3	22.7	22	24	2	5.0	4	6	2	14.0	14	14	2	48.0	48	48
10	5	5	5	23.8	22	28	5	5.8	4	7	3	12.0	11	13	3	47.7	49	47
11	6	5	6	26.1	21	31	4	6.0	5	7	2	13.0	13	13	2	48.0	51	45
12	7	5	7	27.8	25	31	6	12.0	9	15	6	7.8	5	15	6	54.1	60	51
13	16	5	16	25.1	19	29	14	9.9	5	21	5	15.2	10	19	5	51.2	54	47
14	8	5	8	26.5	24	31	8	7.0	4	11	8	12.1	10	19	8	50.6	56	46
19	8	5	8	27.2	25	32	8	5.3	2	8	6	9.3	8	11	6	47.0	50	45
21	7	6	7	25.3	22	29	7	5.0	4	6	4	10.5	10	11	4	48.0	46	51
23	2	4	2	25.2	23	28	1	4.0	4	4	1	11.0	11	11	1	47.0	47	47
24	7	4	7	24.0	22	27	3	5.3	5	6	2	8.0	7	9	2	39.5	39	40
25	10	4	10	24.3	21	27	8	6.9	3	14	6	10.3	9	11	6	45.3	43	50
26	12	5	12	24.0	21	28	13	4.1	3	5	12	10.9	8	16	12	43.9	40	48
27	7	5	7	22.2	19	24	7	3.8	2	5	5	11.4	9	16	5	41.4	39	44
28	20	5	20	24.4	21	26	19	5.1	4	15	16	10.4	9	12	16	44.3	43	47
29	15	6	15	23.4	20	27	15	4.4	3	6	14	10.6	8	14	14	44.2	40	48
30	13	5	13	23.0	19	27	11	4.1	4	5	10	11.4	9	16	10	43.0	40	47
31	13	5	13	23.5	16	29	13	5.5	4	8	8	10.6	10	12	8	44.6	40	50
	212		212	24.45			193	5.7			148	11.76			149	46.91		

Total days incubation for all eggs, 1,178; average incubation period, 5.5.

THE SECOND GENERATION.

THE SECOND BROOD OF EGGS.

Length of incubation.—Egg deposition of the second brood was found to cover a period of practically one month, extending from June 11 to July 12, and only a slight variation in the length of the several incubation observations is noted. It may be found by comparison that this period is practically 14 days shorter than the corresponding period for the first generation. In Table XLIII are included the records for 505 observations. The length of incubation varied here from 4 to 7 days. An average of 4.9 days is described for the entire period.

TABLE XLIII.—*Time of incubation of eggs and length of feeding period of larva, second brood, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of of incubation.	Length of feeding period of larva in specified days.																		Average days.	Minimum days.	Maximum days.	Total. days.
			14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	34				
June 11	12	6	....	....	....	3	2	1	1	2	2	....	1	....	....	....	....	....	....	....	19.8	17	24	238
12	2	7	....	....	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	17.5	17	18	35
13	9	6	....	....	1	2	2	2	1	....	....	....	1	....	....	....	....	....	....	....	18.7	16	24	168
14	25	6	....	1	....	2	3	9	5	4	....	....	....	....	1	....	....	....	....	....	19.4	15	26	484
15	14	5	....	....	1	....	1	4	2	4	....	....	2	....	....	....	....	....	....	....	20.1	16	24	282
16	20	5	....	1	2	1	3	1	4	3	2	....	1	....	2	....	....	....	....	....	20.0	15	26	400
17	40	5	....	....	2	4	4	5	8	7	3	3	1	3	....	....	....	....	....	....	20.2	16	25	808
18	29	6	....	....	....	6	5	4	8	....	4	1	1	....	....	....	....	....	....	....	19.4	17	24	563
19	33	5	....	3	5	8	7	5	2	2	2	....	....	....	....	....	....	....	1	....	17.6	15	30	582
20	19	5	....	....	....	2	....	2	6	1	1	1	1	....	2	1	1	....	1	....	22.0	17	30	419
21	25	5	....	....	....	....	3	4	2	7	3	2	....	3	1	....	....	....	....	....	21.2	18	26	530
22	50	5	....	7	13	8	9	5	3	....	....	1	....	4	....	....	....	....	....	....	17.8	15	25	889
23	34	4	....	....	....	1	7	6	2	6	4	3	2	2	1	....	....	....	....	....	20.7	17	26	704
24	31	4	....	2	4	6	1	3	3	1	2	5	2	2	....	....	....	....	....	....	19.6	15	25	609
25	12	5	....	....	3	2	1	2	2	2	....	....	....	....	....	....	....	....	....	....	18.3	16	21	220
26	20	5	....	....	....	3	5	1	3	3	1	2	....	1	....	....	....	1	....	....	20.3	17	29	405
27	33	5	....	....	4	4	5	1	5	2	3	4	1	....	....	2	1	....	1	....	20.5	16	30	677
28	25	5	....	....	3	3	4	2	1	4	1	1	1	1	1	1	....	2	....	....	20.7	16	29	518
29	25	5	....	3	1	2	1	3	6	4	1	1	....	1	1	....	1	....	....	....	19.9	15	28	498
30	16	4	....	1	3	2	3	4	....	....	2	1	....	....	....	....	....	....	....	....	18.3	15	23	294
July 1	9	5	....	2	2	1	1	....	....	....	....	2	....	....	....	1	....	....	....	1	22.6	15	34	204
3	5	5	....	....	....	1	....	....	1	....	1	....	....	....	....	....	1	....	....	....	21.7	17	28	87
6	4	5	....	....	....	....	....	1	1	....	....	1	1	....	....	....	....	....	....	....	21.5	19	24	86
7	4	5	....	1	....	....	....	....	1	....	1	....	....	....	....	....	1	....	....	....	21.2	15	28	85
9	8	5	....	....	1	1	....	2	....	1	....	2	1	....	....	....	....	....	....	....	20.2	16	24	162
12	2	4	1	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	16.0	14	18	32
	505	....	1	21	45	63	69	67	67	53	33	30	16	17	9	5	5	3	3	1	19.7	....	....	9,979

Total days incubation for all eggs, 2,521; average incubation period, 4.9 days.

THE SECOND BROOD OF LARVÆ.

Length of feeding period.—The feeding period of second-brood larvæ is somewhat shorter than has been recorded for the first-brood larvæ, and is mainly the result of warmer and more settled weather conditions than were prevalent at the time the first-brood larvæ were feeding within the fruit. A more advanced stage of the fruit at this later period of the season was also probably conducive to a shorter feeding period. Of the 505 larvæ of the second brood under observation, one individual insect completed the feeding period in 14 days, the shortest time recorded, while the longest time was 34 days, thus making a range of variation of 20 days. An average of 19.7 days is computed on the whole number under observation, including both wintering larvæ and those transforming the same season. These records will be found in Table XLIII. The average length of the feeding period of larvæ of the first brood was 24.45 days, thus making an average of 4.75 days greater than larvæ of the second brood. Records on the corresponding period obtained during the season of 1912 show an average of 21.23 days.

Feeding period of wintering larvæ.—During the period of observations conducted with individuals of the second brood a total of 505 larvæ was used, and of this number 100 larvæ, or 19.98 per cent, proved to be wintering larvæ. In Table XLIV it is shown that a maximum of 34 days is found to exist for the feeding period and a minimum of 15 days, covering a range of variation of 19 days, with an average feeding period of 21.13 days. This period is 1.43 days greater than the average time for the transforming larvæ of the same brood, and is found to be practically identical with the corresponding period of the second generation during the preceding season.

TABLE XLIV.—*Length of feeding period of wintering larvæ of the second brood of the codling moth, Roswell, N. Mex., 1913.*

Date of egg hatching.	Number of individuals.	Length of feeding in specified days, being the time from hatching of egg to the leaving of fruit by larvæ.																	Average days.	Minimum days.	Maximum days.	Total.
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	34				
June 22	5							3	1			1							22.0	21	25	110
24	8			3	1	2			2										18.8	17	22	151
25	2							1									1		25.5	21	30	51
26	2						1	1											20.5	20	21	41
27	18	1	2		5	1	2	1	1	1		4							20.0	15	25	362
28	5			1						2	1	1							22.4	17	25	112
30	7			1	1	2	1	2											19.2	17	21	135
July 1	7			1	1		2	2	1										19.8	17	22	139
2	10		1		2		1	2	1	1					1		1		21.7	16	30	217
3	13			1	2	1	1	2	1	1		1		1		2			22.2	17	29	289
4	12			1	1	1	2	2	2	2			1						21.0	17	26	252
6	4	1								1				1				1	24.7	15	34	99
8	3						1		1						1				23.3	20	28	70
11	1					1													19.0	19	19	19
12	2								1						1				25.0	22	28	50
14	1		1																16.0	16	16	16
	100	2	4	8	13	8	11	16	11	8	1	7	1	2	3	2	2	1	21.13			2,113

Larval life in the cocoon.—A comparison of the length of the cocooning period of the second generation with the corresponding period of the first generation shows practically no difference, and a fairly constant length of the period may be derived from the figures. Table XLV records the observations with 400 individuals, and while a maximum period is represented by 24 days and a minimum time by 2 days, giving a range of variation of 22 days, the results maintain an average period of only 5.6 days for all larvæ observed. This period is 0.44 day greater than the length of the cocooning period as observed with larvæ of the same generation during the season of 1912.

TABLE XLV.—*The making of cocoons of the second generation of the codling moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.															Average days.	Minimum days.	Maximum days.	Total days.
		2	3	4	5	6	7	8	9	10	11	12	13	14	17	24				
June 11	12	...	1	3	6	2	...	...	...	...	...	...	...	...	...	...	4.8	3	6	57
12	2	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	2.0	4	4	8
13	9	...	...	3	5	...	...	...	1	...	...	...	...	...	...	...	5.1	4	9	46
14	25	...	3	20	1	1	...	...	...	...	...	...	...	...	...	...	4.0	3	6	100
15	14	...	...	6	2	2	1	...	2	1	...	...	...	...	...	...	5.7	4	10	81
16	18	...	1	9	4	1	1	...	...	...	...	1	1	...	...	...	5.4	3	13	97
17	33	...	...	12	8	4	3	2	1	1	...	2	...	...	...	...	5.8	4	12	192
18	23	...	...	4	10	2	5	...	...	1	...	...	...	1	...	...	5.9	4	14	137
19	31	...	5	13	10	2	...	...	...	...	...	...	1	...	...	...	4.6	3	13	142
20	17	...	1	5	2	5	2	1	1	...	...	...	...	...	...	...	5.5	3	9	94
21	23	...	1	3	8	6	3	2	...	...	...	...	...	...	...	...	5.6	3	8	128
22	38	2	1	4	13	4	3	2	3	2	3	1	...	...	...	...	6.3	2	12	241
23	26	...	...	2	8	10	3	2	...	1	...	...	...	...	...	...	6.9	4	10	155
24	26	...	...	8	3	4	5	3	2	1	...	...	...	...	...	...	6.0	4	10	158
25	5	...	...	...	2	2	...	1	...	...	...	...	...	...	...	...	6.0	5	8	30
26	13	...	1	2	4	3	1	...	...	...	1	...	...	...	1	...	6.5	3	17	84
27	23	...	4	2	8	7	1	1	...	...	...	...	...	...	...	...	5.0	3	8	117
28	12	...	...	3	6	1	2	...	...	...	...	...	...	...	...	...	5.1	4	7	62
29	15	...	...	...	5	3	...	1	1	...	...	2	2	...	...	1	8.9	5	24	134
30	14	...	1	6	4	1	...	1	...	1	...	...	...	...	...	...	5.1	3	10	71
July 1	6	...	...	2	2	1	1	...	...	...	...	...	...	...	...	...	5.1	4	7	31
3	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	5.0	5	5	5
6	3	...	...	...	2	...	...	1	...	...	...	...	...	...	...	...	6.0	5	8	18
7	2	...	...	1	...	...	...	...	...	...	1	...	...	...	...	...	7.5	4	11	15
9	9	1	...	1	1	1	1	2	...	1	1	...	...	...	...	...	6.7	2	11	61
	400	3	19	111	115	62	32	19	11	9	6	6	4	1	1	1	5.6	....	....	2,264

SECOND BROOD OF PUPÆ.

Length of pupal stage.—The length of the pupal stage of the second generation as compared with that of the first generation is found to differ very little. Of the 400 insects under observation 1 emerged 7 days after pupation had taken place, while the greater length of time was found to be 20 days. An average period of 11.6 days is shown for the entire number observed. Further reference should be made to Table XLVI.

TABLE XLVI.—*Length of pupal stage of the codling moth in days of all individuals developing from eggs deposited on specified dates, second brood, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of pupal stage in days.														Average days.	Minimum days.	Maximum days.	Total days.
		7	8	9	10	11	12	13	14	15	16	17	18	19	20				
June 11	12	...	...	...	5	5	2	...	...	...	...	...	...	...	...	10.8	10	12	129
12	2	...	...	1	1	...	...	...	...	...	...	...	...	...	...	9.5	9	10	19
13	13	...	...	...	...	5	3	1	...	...	...	...	...	...	...	11.5	11	13	104
14	25	1	...	2	5	5	8	4	...	...	...	...	...	...	...	11.1	7	13	278
15	14	...	...	1	1	5	4	2	...	1	...	...	...	...	...	11.6	9	15	163
16	18	...	...	2	1	4	6	2	...	1	2	...	...	...	...	12.0	9	16	217
17	33	...	1	...	5	6	13	3	...	3	...	...	1	1	...	12.2	8	19	401
18	23	...	...	...	1	1	15	4	1	...	1	...	...	...	...	12.3	10	16	283
19	31	...	...	1	6	14	6	3	...	1	...	...	...	...	...	11.2	9	15	349
20	17	...	...	1	...	10	3	2	1	...	...	...	...	...	...	11.5	9	14	195
21	23	...	...	...	4	10	6	1	2	...	...	...	...	...	...	11.4	10	14	263
22	38	...	...	2	3	16	7	3	3	3	...	1	...	...	...	11.6	9	17	451
23	26	...	...	...	6	10	7	2	1	...	...	...	...	...	...	11.3	10	14	294
24	26	...	...	...	4	17	4	...	...	...	1	...	...	...	...	11.1	10	16	291
25	5	...	...	...	2	2	...	...	...	...	...	1	...	...	...	11.8	10	17	59
26	13	...	...	4	3	5	...	...	...	1	...	...	...	...	...	10.4	9	15	136
27	23	...	...	1	8	11	1	...	...	...	...	1	...	...	1	11.2	9	20	259
28	12	...	...	1	4	5	...	...	...	...	...	2	...	...	...	11.5	9	17	138
29	15	...	...	1	6	4	2	...	...	1	...	...	...	1	...	11.4	9	19	171
30	14	...	...	1	4	5	4	...	...	...	...	...	...	...	...	10.8	9	12	152
July 1	6	...	...	1	2	2	...	...	1	...	...	...	...	...	...	10.8	9	14	65
3	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	9.0	9	9	9
6	3	...	...	...	3	...	...	...	...	...	...	...	...	...	...	10.0	10	10	30
7	2	...	...	...	1	...	1	...	...	...	...	...	...	...	...	11.0	10	12	22
9	7	...	1	3	2	1	...	...	...	...	...	...	...	...	...	9.4	8	11	66
12	2	...	...	...	1	...	1	...	...	...	...	...	...	...	...	11.0	10	12	22
	400	1	2	23	78	143	93	27	9	11	4	5	1	2	1	11.6	......	......	4,566

LENGTH OF LIFE CYCLE.

The length of time elapsing from the date of egg deposition to emergence of moth of the same generation for 407 individual insects is shown in Table XLVII. Of this number one insect completed the life cycle in 28 days, while the longest time recorded was 59 days. An average period of 41.4 days is described for the entire number observed, being 5.5 days shorter than the corresponding period of the first generation, and 0.14 day greater than the length of life cycle of the second generation of the insect as observed during the season of 1912.

TABLE XLVII.—*Length of life cycle of second generation of codling moth from time of egg deposition to emergence of moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Moths emerged in specified days from time of deposition of eggs of the same generation.																						Average days.	Minimum days.	Maximum days.	Total days.
		28	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	54	59				
June 11	13							2	3	2		1	3	1		1								41.07	38	46	534
12	2							2																38.0	38	38	76
13	9						1		1	2	2		1		1	1								41.3	37	46	372
14	26				1	2	1	2	3	3	5	3	2	2	1				1					40.6	35	49	1,056
15	14				1				3	1	1	1		3		2		1	1					42.6	35	49	596
16	19		1	1			1		1	1	3	3	2		1	1	1	1		1	1			42.4	33	51	805
17	34				1		2	1	1	1	6	4	4	3		3	4	2	1	1				43.1	35	50	1,465
18	24								1	3	3	1	3	4	5	2				1		1		43.8	39	54	1,050
19	32			1	4	5	3	3	2	6	5	1		1					1					38.7	34	49	1,237
20	17								2	2		3	1	4		1	1	1	2					43.6	39	49	742
21	23								1	2	2	6	1	6			5							43.3	39	47	995
22	38				1	3	1	2	3	4	12	6	3		2	1								40.6	35	46	1,542
23	26							1	5	3	3	4	1	4	4	1								41.9	38	46	1,089
24	26				3			3	2	5	5	2	3	1	2									40.3	35	45	1,049
25	5					1	1			1		1		1										39.8	36	44	199
26	13						2		3		1		2	1	1		1	1	1					42.3	37	49	551
27	23	1					3	2	4	2	1	2	2	4		1	1							40.4	28	47	931
28	12						1	3	1	2			4				1							40.8	37	47	489
29	15						2			2	1		2	1	1	1		3	1				1	47.8	37	59	668
30	14			1	1	2	6		1	1		1		1										37.7	34	44	528
July 1	6					1	3	1								1								38.5	36	46	231
3	2		1			1																		34.5	33	36	69
6	3												2	1										43.3	43	44	130
7	2			1														1						41.0	34	48	82
9	7								2	1			2		1	1								42.1	39	46	295
12	2		1									1												37.5	33	42	75
	407	1	3	4	12	15	27	22	39	44	50	40	38	38	19	17	14	10	8	3	1	1	1	41.4	......	......	16,856

SECOND BROOD OF MOTHS.

Egg deposition.—A total of 38 individual female moths of the second brood emerging in the interval between July 14 and August 17 were isolated in order to obtain oviposition records as shown by moths in confinement. Reference to Table XLVIII will show that a total of 4,847 eggs were deposited by the 38 females, an average oviposition of 127.55 per individual. The maximum individual oviposition was 259 eggs. The average individual oviposition per day was 16.6 eggs, and the maximum daily oviposition per female was 108 eggs. On an average the length of the oviposition period was 8.3 days, although the maximum length of the period was 16 days. It was also found that actual oviposition by an individual female may occur on 14 separate days, but the average number found in this connection is 7.6 days. The observations showed that it was possible for oviposition to begin as early as one day following emergence, although the average length of time was 3.68 days. The longevity of the moths thus confined varied considerably, one insect living but 6 days, while another individual persisted for 21 days after emergence. The average length of life of the moths in this connection was 12.8 days.

TABLE XLVIII.—*Egg deposition by individual codling moths of the second brood, Roswell, N. Mex., 1913.*

Moth No.	Date of emergence of moths.	Date of oviposition and number of eggs deposited.																																									
		July.														August.																											
		18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	July 14	32	5	9	4	16	18	17	3																																		
2	16	56	8	3	59	26	27	24	14	19	3																																
3	16	36	29	46	23	23	21																																				
4	16				5	6	13	24	10																																		
5	18					1	4	2	3	6	3	2	8	3	15	4	5	4	14																								
6	18				27	21	14																																				
7	20									4	9	44	34	14	45	13	14																										
8	20								12		32	7	13	12	38																												
9	20								3		6	4	13	6	12	21	2	6	5																								
10	24								52	64	60	40	21																														
11	24												3		41	8	18	43	17																								
12	24											1	12	22	35	24	11																										
13	24												2		4	24	4	17	35	22	10	3																					
14	24								61	44	45	24	5	23	24	16	17																										
15	28														9	11	7	12	8	9	6																						
16[1]	28												69	3	58																												
17[1]	28												80	36																													
18	28												1	14	34	7			1	20	8																						
19	28												5	47	30		1		17																								
20	30														66	40	9	20	22	54	24		1																				
21	30															35	63	3																									
22	Aug. 2																						1	6	5	2	6	35															
23	2																	5	108	38	36																						
24	8																										1	20		10	20	55		4	4								
25	9																									2	14	10	55	3	20	10	41	1	8								
26	9																											1	1	9		2	1	6	29	3	2	18		9	8	15	10
27	9																															4	9	1	4	14	19	25	3				
28	10																									9	9	7	2	10	26												
29	10																											3		15		12	8	10	15	12	10	9	15	22	8	13	4
30	10																												6		17	4	11	4	41	4	6	12	15				
31	13																												9				3	41	4	14	3	27	14	45			
32	13																													1	10			2	2	6	4	14		6	32	4	28
33	13																													6	20	2	5	14	32								
34	13																														6	3	4	4	21	8	15	22	7	14	18	1	2
35	15																																1	1	4	15	18	6	7	4		2	
36	15																														3	14	77	4	38	20	17	5	15	25			
37	15																																			27	11		5	3	35	8	
38	17																																	30	53		14	47	5	7	23	12	
Total		124	42	58	118	93	97	67	158	137	158	122	266	180	411	203	151	110	227	143	84	3	2	6	5	13	30	76	73	54	122	106	160	122	255	123	119	185	86	135	124	55	44

[1] Moth escaped before record was completed.

TABLE XLVIII.—*Egg deposition by individual codling moths of the second brood, Roswell, N. Mex., 1913*—Continued.

Moth No.	Date of emergence of moths.	Death of moth.	Total number of eggs per moth.	Length of period before first oviposition.	Period from first to last oviposition.	Period from emergence to last oviposition.	Life of moth after last oviposition.	Total length of life of moth.	Number of days on which oviposition[1] occurred.	Average number of eggs per oviposition per female.
				Days.	*Days.*	*Days.*	*Days.*	*Days.*		
1	July 14	July 27	104	4	8	11	2	13	8	13.0
2	16	28	239	2	10	11	1	12	10	23.9
3	16	25	178	2	6	7	2	9	6	29.6
4	16	27	58	5	5	9	2	11	5	11.6
5	18	Aug. 6	74	4	14	17	2	19	14	5.2
6	18	July 24	62	3	3	5	1	6	3	20.6
7	20	Aug. 3	177	6	8	13	1	14	8	22.1
8	20	3	114	5	7	11	3	14	6	19.0
9	20	6	78	5	11	15	2	17	10	7.8
10	24	1	237	1	5	5	3	8	5	47.4
11	24	6	130	5	7	11	2	13	6	21.7
12	24	4	105	4	6	9	2	11	6	16.6
13	24	9	121	5	10	14	2	16	9	13.3
14	24	8	259	1	9	9	5	15	9	28.7
15	28	8	62	3	7	9	2	11	7	8.8
16[1]	28	....	130	1	3	3	....	....	3	43.3
17[1]	28	....	116	1	2	2	....	....	2	58.0
18	28	12	85	1	9	9	6	15	7	12.1
19	28	5	100	1	7	7	1	8	5	20.0
20	30	10	236	1	9	9	2	11	8	29.5
21	30	6	101	2	3	4	3	7	3	33.6
22	Aug. 2	16	55	6	7	12	2	14	6	9.2
23	2	8	187	1	4	4	2	6	4	46.7
24	8	23	114	5	9	13	2	15	7	16.3
25	9	26	164	3	10	12	5	17	10	16.4
26	9	30	114	5	16	20	1	21	14	8.2
27	9	27	79	9	8	16	2	18	8	9.9
28	10	21	63	2	6	7	4	11	6	10.5
29	10	31	156	4	16	9	2	21	14	11.1
30	10	27	120	5	11	10	2	17	10	12.0
31	13	30	160	2	12	13	4	17	9	17.7
32	13	Sept. 1	109	3	14	16	3	19	11	9.9
33	13	Aug. 23	79	3	6	8	2	10	6	13.2
34	13	30	125	4	13	16	1	17	13	9.5
35	15	29	58	4	10	13	1	14	9	6.4
36	15	28	218	2	10	11	2	13	10	21.8
37	15	29	89	7	7	13	1	14	6	14.8
38	17	30	191	3	9	11	2	13	8	23.8
Total	....	....	4,847	....	....	....	....	....	....	....

[1] Moth escaped before record was completed.

	Average.	Maximum.	Minimum.
Number of days from emergence of moth to first oviposition	3.68	9	1
Number of eggs deposited by each female	127.55	259	55
Number of eggs deposited per day per female	16.6	108	1
Length of oviposition period in days	8.3	16	2
Number of days of actual oviposition	7.6	14	2
Number of days from emergence of moth to last oviposition	10.6	20	2
Number of days moth lived after last oviposition	2.15	6	1
Length of life of moth in days	12.8	21	6

SUMMARY OF RECORDS FOR SECOND GENERATION.

In Table XLIX there appears a summary of the records on the time development of the codling moth of the second generation in the stages of egg, larva, and pupa. The sum of the average periods spent in the several stages totals 41.8 days as compared with 41.4 days given as the average length of the life cycle of the second generation. These figures compare very closely with corresponding data obtained during 1912.

TABLE XLIX.—*Summary of records on the time of development of the codling moth, second generation, in the stages of egg, larva, and pupa, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Number of individuals.	Length of feeding larva.			Number of individuals.	Length of cocooning period.			Number of individuals.	Length of pupal stage.			Number of individuals.	Total length of life cycle.		
				Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.
June 11	13	6	12	19.8	17	24	12	4.8	3	6	12	10.8	10	12	13	41.07	38	46
12	2	7	2	17.5	17	18	2	2.0	4	4	2	9.5	9	10	2	38.0	38	38
13	9	6	9	18.7	16	24	9	5.1	4	9	9	11.5	11	13	9	41.3	37	46
14	26	6	25	19.4	15	26	25	4.0	3	6	25	11.1	7	13	26	40.6	35	49
15	14	5	14	20.1	16	24	14	5.7	4	10	14	11.6	9	15	14	42.6	35	49
16	20	5	20	20.0	15	26	18	5.4	3	13	18	12.0	9	16	19	42.4	33	51
17	40	5	40	20.2	16	25	33	5.8	4	12	33	12.2	8	19	34	43.1	35	50
18	29	6	29	19.4	17	24	23	5.9	4	14	23	12.3	10	16	24	43.8	39	54
19	33	5	33	17.6	15	30	31	4.6	3	13	31	11.2	9	15	32	38.7	34	49
20	19	5	19	22.0	17	30	17	5.5	3	9	17	11.5	9	14	17	43.6	39	49
21	25	5	25	21.2	18	26	23	5.6	3	8	23	11.4	10	14	23	43.3	39	47
22	50	5	50	17.8	15	25	38	6.3	2	12	38	11.6	9	17	38	40.6	35	46
23	34	4	34	20.7	17	26	26	6.9	4	10	26	11.3	10	14	26	41.9	38	46
24	31	4	31	19.6	15	25	26	6.0	4	10	26	11.1	10	16	26	40.3	35	45
25	12	5	12	18.3	16	21	5	6.0	5	8	5	11.8	10	17	5	39.8	36	44
26	20	5	20	20.3	17	29	13	6.5	3	17	13	10.4	9	15	13	42.3	37	49
27	33	5	33	20.5	16	30	23	5.0	3	8	23	11.2	9	20	23	40.4	28	47
28	25	5	25	20.7	16	29	12	5.1	4	7	12	11.5	9	17	12	40.8	37	47
29	25	5	25	19.9	15	28	15	8.9	5	24	15	11.4	9	19	15	47.8	37	59
30	16	4	16	18.3	15	23	14	5.1	3	10	14	10.8	9	12	14	37.7	34	44
July 1	9	5	9	22.6	15	34	6	5.1	4	7	6	10.8	9	14	6	38.5	36	46
3	4	5	4	21.7	17	28	1	5.0	5	5	1	9.0	9	9	2	34.5	33	36
6	4	5	4	21.5	19	24	3	6.0	5	8	3	10.0	10	10	3	43.3	43	44
7	4	5	4	21.2	15	28	2	7.5	4	11	2	11.0	10	12	2	41.0	34	48
9	8	5	8	20.2	16	24	9	6.7	2	11	7	9.4	8	11	7	42.1	39	46
12	2	4	2	16.0	14	18	....	....	....	....	2	11.0	10	12	2	37.5	33	42
	507	....	505	19.7	....	....	400	5.6	....	....	400	11.6	....	....	407	41.4	....	....

Total days incubation for all eggs, 2,533; average incubation period, 4.9.

THE THIRD GENERATION.

THIRD BROOD OF EGGS.

Time of incubation.—Eggs of the third brood were found in the field July 10, and deposition continued more or less regularly until August 11, a period of slightly more than one month. The length of this period of deposition is found by comparison to be practically identical with that of the second brood, but is exceeded by the corresponding period of the first brood by 13 days. Of 180 observations made, an average incubation period of 5.3 days is found. These records appear in Table L. In comparing this period with average incubation periods of the previous broods, it will be noted that the first brood experienced a somewhat longer incubation period, it being 5.96 days, while that of the second brood was somewhat shorter, 4.9 days.

TABLE L.—*Time of incubation of eggs of the codling moth and length of feeding period of third brood larvæ, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Length of feeding period of larva in specified days.														Average days.	Minimum days.	Maximum days.	Total days.
			15	16	17	18	19	20	21	22	23	24	25	26	27	28				
July 10	12	5	......	1	1	6	......	2	......	1	......	......	1	......	......	......	19.0	16	25	228
13	1	6	......	......	......	......	......	1	......	......	......	......	......	......	......	......	20.0	20	20	20
14	14	5	......	......	1	......	3	1	4	3	......	......	......	......	2	......	21.2	17	27	298
15	19	5	......	......	1	2	3	6	1	3	......	1	1	......	1	......	20.6	17	27	393
16	7	5	......	......	......	1	1	2	1	2	......	......	......	......	......	......	20.2	18	22	142
17	11	6	......	......	1	4	1	2	3	......	......	......	......	......	......	......	19.1	17	21	211
18	15	7	......	3	1	3	2	1	......	1	......	......	1	......	1	2	20.4	16	28	307
19	2	6	......	......	......	......	1	1	......	......	......	......	......	......	......	......	19.5	19	20	39
20	9	6	2	......	......	......	1	1	......	1	2	1	......	1	......	......	20.7	15	26	187
21	12	6	1	......	......	4	2	......	......	1	2	1	......	......	1	......	20.3	15	27	244
22	1	5	......	......	......	......	1	......	......	......	......	......	......	......	......	......	19.0	19	19	19
23	8	5	......	......	......	2	2	3	......	1	......	......	......	......	......	......	19.5	18	22	156
24	16	5	......	......	1	......	1	2	2	6	......	2	1	......	1	......	21.9	17	27	350
25	8	5	......	1	......	1	2	......	......	3	1	......	......	......	......	......	20.1	16	23	161
26	5	5	......	......	......	1	4	......	......	......	......	......	......	......	......	......	18.8	18	19	94
27	2	6	......	......	......	2	......	......	......	......	......	......	......	......	......	......	18.0	18	18	36
28	4	5	......	......	......	2	......	......	......	......	......	......	1	......	1	......	22.0	18	27	88
29	7	5	......	2	......	......	1	1	......	1	1	1	......	......	......	......	20.0	16	24	140
30	6	5	......	1	......	......	2	2	1	......	......	......	......	......	......	......	19.1	16	21	115
31	4	5	......	......	1	1	......	2	......	......	......	......	......	......	......	......	18.7	17	20	75
Aug. 1	5	5	......	......	2	2	......	1	......	......	......	......	......	......	......	......	18.0	17	20	90
3	2	6	......	......	1	......	......	......	......	......	1	......	......	......	......	......	20.0	17	23	40
5	1	5	......	......	......	......	1	......	......	......	......	......	......	......	......	......	19.0	19	19	19
6	7	5	......	3	1	......	2	......	1	......	......	......	......	......	......	......	17.7	16	21	124
11	2	5	......	......	2	......	......	......	......	......	......	......	......	......	......	......	17.0	17	17	34
	180	....	3	11	13	31	30	28	13	23	7	6	5	1	7	2	20.0	....	....	3,610

Total days incubation for all eggs, 969; average incubation period, 5.3 days.

THIRD BROOD OF LARVÆ.

Length of feeding period.—In Table L are also found the records on the length of the feeding period of transforming larvæ of this generation. Of the 180 individual insects under observation in this connection the results show that 31 of the number completed the stage within 18 days. The maximum number of feeding days is 28, the minimum number 15, and the average is 20 days for the whole series. This average is found to be somewhat greater than the corresponding average for the second brood, but is 4.45 days shorter than the same time for the first brood.

Feeding period of wintering larvæ.—Of the 722 larvæ of the third brood under observation in this connection, 542 or 75.06 per cent, were found to be wintering larvæ. The maximum length of the feeding period of the wintering larvæ was 35 days, as contrasted with the maximum of 28 days, which is the longest corresponding period for transforming larvæ of the same brood. The shortest feeding period recorded is 14 days, while an average of 21.1 days exceeds the average period for the transforming larvæ by only 1.1 days. See Table LI.

TABLE LI.—*Length of feeding period of wintering codling-moth larvæ of the third brood, Roswell, N. Mex., 1913.*

Date of hatching of eggs.	Number of individuals.	Length of feeding in specified days, being the time from hatching of eggs to the leaving of fruit by larvæ. 14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Average days.	Maximum days.	Minimum days.	Total days.
July 15	29	....	....	....	3	4	6	1	7	1	....	5	2	....	....	....	....	....	....	....	....	....	....	20.6	25	17	596
16	8	....	....	....	....	....	....	1	3	1	1	....	1	....	....	....	....	....	1	....	....	....	....	23.0	31	20	184
18	9	....	....	....	....	2	1	2	1	2	....	1	....	....	....	....	....	....	....	....	....	....	....	20.4	24	18	184
19	15	....	....	....	1	2	6	2	1	1	1	....	....	....	1	....	....	....	....	....	....	....	....	20.0	27	17	300
20	34	....	....	....	2	3	4	11	6	1	2	1	2	1	....	1	....	....	....	....	....	....	....	20.8	28	17	706
21	19	....	....	....	2	2	2	2	5	....	....	1	....	1	1	....	2	....	....	....	....	1	....	22.2	34	17	422
23	10	....	....	....	2	....	....	3	....	1	....	....	....	....	....	2	....	1	....	....	....	....	1	23.7	35	17	237
24	19	....	....	1	1	1	2	5	....	3	....	....	....	4	....	....	2	....	....	....	....	....	....	21.9	29	16	417
25	7	....	....	....	....	....	....	....	1	1	....	1	1	2	1	....	....	....	....	....	....	....	....	24.4	27	21	171
26	16	....	1	....	....	2	1	2	1	....	5	....	2	....	1	1	....	....	....	....	....	....	....	21.9	28	15	351
27	13	....	1	....	1	....	4	....	1	....	1	2	2	....	1	....	....	....	....	....	....	....	....	21.3	27	15	277
28	22	....	....	....	....	....	....	6	5	1	1	2	1	....	1	5	....	....	....	....	....	....	....	23.2	28	20	510
29	24	....	....	....	1	....	3	4	1	3	1	2	1	2	1	2	....	1	....	....	2	....	....	23.7	33	17	568
30	38	....	1	1	1	7	16	1	1	3	3	3	....	....	....	....	....	....	....	1	....	....	....	19.9	32	15	758
31	43	....	1	1	1	7	4	3	3	4	6	5	3	1	....	....	....	1	2	....	....	1	....	22.0	34	15	946
Aug. 1	38	....	....	3	8	2	4	5	4	3	3	2	....	....	1	1	1	1	....	....	....	....	....	20.4	30	16	777
2	27	....	....	....	4	4	1	6	3	5	....	1	1	....	1	1	....	....	....	....	....	....	....	20.6	28	17	556
3	13	....	....	1	....	2	1	2	....	4	2	1	....	....	....	....	....	....	....	....	....	....	....	20.7	24	16	269
4	22	....	....	....	....	2	10	3	1	1	3	....	1	....	....	1	....	....	....	....	....	....	....	20.5	28	18	451
6	20	....	....	1	8	4	....	3	1	....	2	1	....	....	....	....	....	....	....	....	....	....	....	18.8	24	16	375
7	27	....	1	8	7	3	2	....	1	1	1	....	1	....	2	....	....	....	....	....	....	....	....	18.5	27	15	499
8	24	....	....	1	1	2	1	....	2	3	2	3	3	....	3	1	1	1	....	....	....	....	....	23.2	30	16	557
10	16	....	....	....	2	....	8	....	1	1	....	....	1	1	....	2	....	....	....	....	....	....	....	21.0	28	17	336
11	7	....	2	1	2	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17.1	21	15	120
12	8	....	1	....	....	....	....	1	2	1	1	....	2	....	....	....	....	....	....	....	....	....	....	21.5	25	15	172
16	7	....	....	....	....	1	2	1	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	20.1	23	18	141
20	8	....	....	....	....	....	....	2	2	1	....	1	1	1	....	....	....	....	....	....	....	....	....	22.4	26	20	179
22	7	....	1	....	....	....	2	....	....	....	....	1	2	1	....	....	....	....	....	....	....	....	....	21.9	26	19	153
24	5	....	....	....	1	1	1	....	....	2	....	....	....	....	....	....	....	....	....	....	....	....	....	19.6	22	17	98
26	7	....	2	1	....	....	....	....	2	2	....	....	....	....	....	....	....	....	....	....	....	....	....	18.9	22	15	132
	542	....	11	19	48	51	82	66	58	46	36	33	27	14	14	17	6	5	3	1	2	2	1	21.1	....	....	11,442

Larval life in the cocoon.—Observations in this case were made with 180 individual insects to determine the length of the cocooning period. The longest single period was found to be 19 days, and the minimum period 2 days, while an average of 6.2 days prevailed. This is somewhat longer than the average of 5.7 days found for the corresponding period for the first brood and 5.6 days for the second generation. The results of these observations appear in Table LII.

TABLE LII.—*The making of cocoons of third-brood larvæ of the codling moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.															Average days.	Minimum days.	Maximum days.	Total days.
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	19				
July 10	12			3	5			3	1								5.8	4	9	70
13	1			1													4.0	4	4	4
14	14			3	2	1	4	1	1			1				1	7.4	4	19	104
15	19		1	2	3	5	5	1	1		1						6.3	3	11	119
16	7		1	3		2	1										4.8	3	7	34
17	11	1	1	2	4	3											4.6	2	6	51
18	15		3	4	6		1								1		5.1	3	15	77
19	2			1		1											5.0	4	6	10
20	9		2	3	1	1			1		1						5.4	3	11	49
21	12		2	2	5	3											4.7	3	6	57
22	1			1													4.0	4	4	4
23	8		1	5	1	1											4.2	3	6	34
24	16			1	5	3	2		1	1	1	2					7.1	4	12	115
25	8				1		3		2		1			1			8.6	5	14	69
26	5					3	1				1						7.2	6	11	36
27	2					1		1									7.0	6	8	14
28	4				1	1	1						1				7.7	5	13	31
29	7						3	1	1	1	1						8.4	7	11	59
30	6				1	1	1		2		1						7.8	5	11	47
31	4		1				1	1		1							7.0	3	10	28
Aug. 1	5			1	1	1		1	1								6.4	4	9	32
3	2	1					1										4.5	2	7	9
5	1							1									8.0	8	8	8
6	7	1			3	1	1	1									5.4	2	8	38
11	2							1	1								8.5	8	9	17
	180	3	12	32	39	28	25	12	12	3	7	3	1	1	1	1	6.2	....	....	1,116

THIRD BROOD OF PUPÆ.

Length of pupal stage.—The observations made on the length of the pupal stage of the third brood, as found in Table LIII, show that of the entire number of 180 individuals accounted for, 53 of that number completed the pupal period in 11 days. The maximum length of the stage is shown to be 17 days and the minimum time 7 days. The average is found to be 11.4 days and this is practically identical in length with that of the corresponding period of the preceding brood, 11.6 days, and is exceeded only slightly by the corresponding average for the first brood, namely, 11.76 days. The average pupal period for the spring brood, 22.97 days, is found to be almost twice as long as that of succeeding generations of the same season.

TABLE LIII.—*Length of pupal stage of the codling moth in days of all individuals developing from eggs deposited on specified dates, third brood, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Length of pupal stage in days.											Average days.	Minimum days.	Maximum days.	Total days.
		7	8	9	10	11	12	13	14	15	16	17				
July 10	12	....	....	2	7	2	1	....	....	....	....	....	10.1	9	12	122
13	1	....	....	....	1	....	....	....	....	....	....	....	10.0	10	10	10
14	14	....	....	1	2	8	2	1	....	....	....	....	11.0	9	13	154
15	19	....	....	3	8	7	1	....	....	....	....	....	10.3	9	12	196
16	7	....	....	....	1	5	1	....	....	....	....	....	11.0	10	12	77
17	11	....	....	....	1	7	2	1	....	....	....	....	11.2	10	13	124
18	15	....	....	2	2	6	2	3	....	....	....	....	11.1	9	13	167
19	2	....	....	....	....	2	....	....	....	....	....	....	11.0	11	11	22
20	9	....	....	....	3	1	3	....	....	1	....	1	12.1	10	17	109
21	12	....	....	2	4	2	2	1	1	....	....	....	10.9	9	14	131
22	1	....	....	....	....	1	....	....	....	....	....	....	11.0	11	11	11
23	8	....	....	....	1	3	4	....	....	....	....	....	11.3	10	12	91
24	16	....	....	2	3	3	5	2	....	....	1	....	11.4	9	16	183
25	8	....	....	1	1	1	3	1	1	....	....	....	11.6	9	14	93
26	5	....	....	....	1	1	....	2	1	....	....	....	12.2	10	14	61
27	2	....	....	1	....	1	....	....	....	....	....	....	10.0	9	11	20
28	4	....	....	....	....	....	....	3	1	....	....	....	13.2	13	14	53
29	7	1	....	....	1	1	....	1	1	1	1	....	12.2	7	16	86
30	6	....	1	....	....	....	2	1	1	1	....	....	12.3	8	15	74
31	4	....	....	1	....	1	....	....	2	....	....	....	12.0	9	14	48
Aug. 1	5	....	....	....	....	1	1	....	3	....	....	....	13.0	11	14	65
3	2	....	....	....	....	....	....	1	....	1	....	....	14.0	13	15	28
5	1	....	....	....	....	....	....	1	....	....	....	....	13.0	13	13	13
6	7	....	....	....	1	....	....	1	....	3	2	....	14.2	10	16	100
11	2	....	....	....	....	....	2	....	....	....	....	....	12.0	12	12	24
	180	1	1	15	37	53	31	19	11	7	4	1	11.4	......	......	2,062

LENGTH OF LIFE CYCLE.

A study of Table LIV will show that of 185 individual insects which completed the life cycle of the third generation, two passed through the several stages in 34 days, this being the shortest time recorded. Also that one insect required a maximum time of 58 days, and that an average of 43.11 days is found for the entire number. This period in comparison with the average length of life cycle of previous generations is shown to be 1.71 days greater than the corresponding period for the second brood and 3.8 days shorter than the same period for the first generation. The average period for the length of the life cycle for the third generation during 1912 was 48.57 days, a difference of 5.46 days.

TABLE LIV.—*Length of life cycle of third generation of codling moth from time of egg deposition to emergence of moth, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Moths emerged in specific days from time of deposition of eggs from same generation.																						Average days.	Minimum days.	Maximum days.	Total days.
		34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	53	55	57	58				
July 10	13			3	3			2	3		1								1					39.7	36	51	516
13	1							1																40.0	40	40	40
14	14							2	2	1		4	1	1		1	1						1	44.7	40	58	626
15	22	1		1			1	3	2	1	3	4	2	1	3									42.5	34	47	935
16	7				1		1			3	2													41.1	37	43	288
17	11			1	1		1		3		3	2												41.0	36	44	452
18	15				3		1	2	1	1			1	1	1	1			1	2				43.7	37	53	656
19	2							1			1													41.5	40	43	83
20	9		2			1				1				1		1	1		1		1			44.3	35	55	399
21	13	1			1	1	2		1	1	2					1	1		2					35.0	34	51	555
22	1						1																	39.0	39	39	39
23	8				1	1		2	3		1													40.1	37	43	321
24	16						1	1		2		4	2			3	2					1		45.5	39	57	728
25	8									1	1	1	1	2	1			1						45.3	42	50	363
26	5								1		2	1	1											43.2	41	45	216
27	2						1				1													41.0	39	43	82
28	4										1						1	2						48.0	43	50	192
29	7								1	1	1			2					2					45.7	41	51	320
30	6									2	1		1		2									44.3	42	47	266
31	4					1	1								2									42.7	38	47	171
Aug. 1	5					1	1						3											42.4	38	45	212
3	2											1	1											44.5	44	45	89
5	1												1											45.0	45	45	45
6	7					1		1	1	1		2				1								42.4	38	48	297
11	2									1	1													42.5	42	43	85
	185	2	2	5	10	6	11	15	18	16	21	19	14	8	9	8	6	3	7	2	1	1	1	43.11	....	....	7,976

THIRD BROOD OF MOTHS.

Time of emergence.—Because of a slight overlapping of the periods of emergence of moths of the second and third broods transforming from larvæ collected from banded trees in orchards, the records showing the time of emergence of moths of the two broods are consolidated and appear in Table LV.

The data show the first emergence of moths of the second generation to have occurred July 6, and a maximum number of moths of this brood to have appeared on August 6, or practically one month later. Emergence continued quite irregularly until September 19, although moths of the third brood apparently reached a maximum of emergence on August 28. The variations in the periods of emergence of the two broods shown by means of curves appear in figure 10, and illustrate very concisely the features of the periods and the time of occurrence.

TABLE LV.—*Time of emergence of codling moths of the second and third broods, Roswell, N. Mex., 1913.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 6	1	Aug. 13	151
7	18	14	146
8	20	15	96
9	34	16	112
10	24	17	115
11	52	18	97
12	34	19	109
13	35	20	59
14	56	21	52
15	31	22	74
16	40	23	40
17	54	24	33
18	40	25	60
19	98	26	29
20	97	27	42
21	47	28	57
22	88	29	47
23	157	30	28
24	201	31	36
25	125	Sept. 1	47
26	260	2	28
27	331	3	19
28	420	4	22
29	297	5	15
30	431	6	19
31	457	7	20
Aug. 1	404	8	18
2	399	9	20
3	362	10	11
4	473	11	10
5	411	12	2
6	475	13	4
7	409	14	7
8	401	15	8
9	329	16	3
10	301	17	1
11	250	19	2
12	134		

SUMMARY OF RECORDS.

In Table LVI may be found a comparatively complete summary of records on the several stages of the life cycle of the codling moth of the third generation, showing the average length of the periods of each stage. The sum of the averages of the stages is found to be

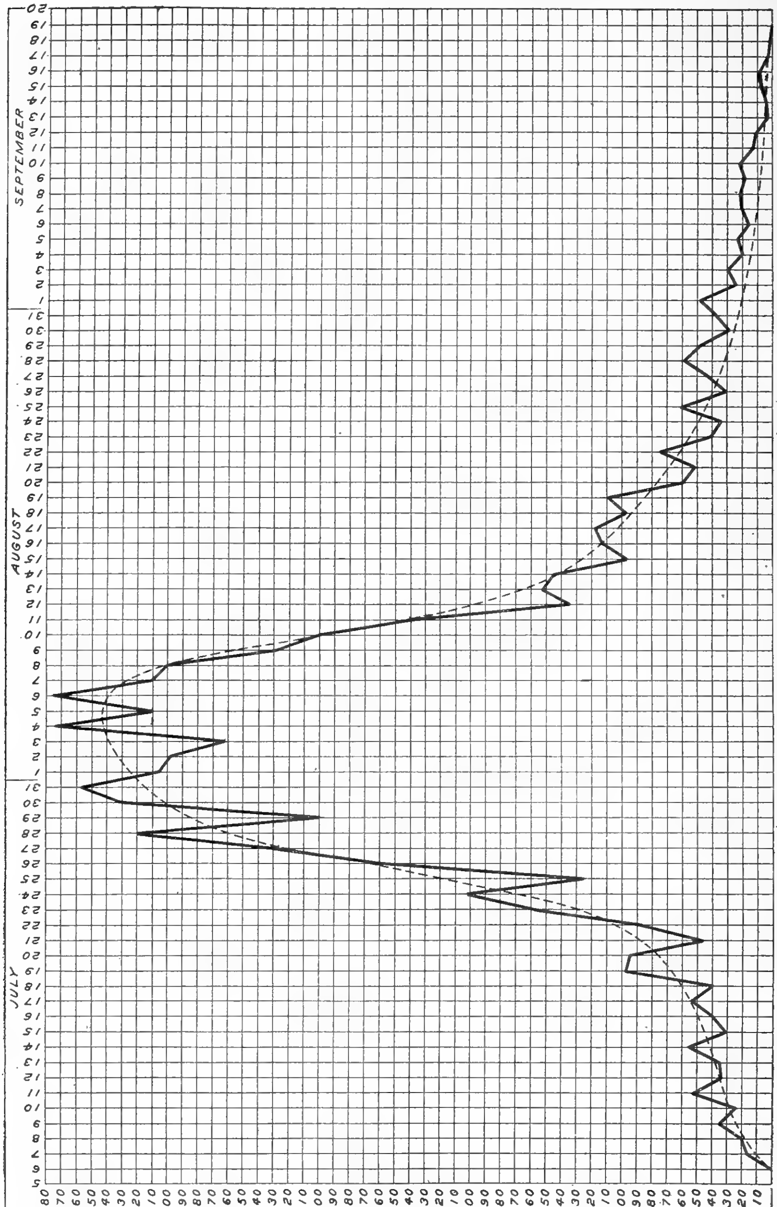

FIG. 10.—Curve showing emergence of codling moths of second and third broods, Roswell, N. Mex., 1913. (Original.)

42.9 days, while the average length of the total life cycle of this generation is 43.11 days, a difference of but 0.2 days.

TABLE LVI.—*Summary records on the time of development of the codling moth of the third generation in its stages of egg, larva, and pupa, Roswell, N. Mex., 1913.*

Date of egg deposition.	Number of individuals.	Days of incubation.	Number of individuals.	Length of feeding larva.			Number of individuals.	Length of cocooning period.			Number of individuals.	Length of pupal stage.			Number of individuals.	Total length of life cycle.		
				Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.		Average days.	Minimum days.	Maximum days.
July 10	13	5	12	19.0	16	25	12	5.8	4	9	12	10.1	9	12	13	39.7	36	51
13	1	6	1	20.0	20	20	1	4.0	4	4	1	10.0	10	10	1	40.0	40	40
14	14	5	14	21.2	17	27	14	7.4	4	19	14	11.0	9	13	14	44.7	40	58
15	22	5	19	20.6	17	27	19	6.3	3	11	19	10.3	9	12	22	42.5	34	47
16	7	5	7	20.2	18	22	7	4.8	3	7	7	11.0	10	12	7	41.1	37	43
17	11	6	11	19.1	17	21	11	4.6	2	6	11	11.2	10	13	11	41.0	36	44
18	15	7	15	20.4	16	28	15	5.1	3	15	15	11.1	9	13	15	43.7	37	53
19	2	6	2	19.5	19	20	2	5.0	4	6	2	11.0	11	11	2	41.5	40	43
20	9	6	9	20.7	15	26	9	5.4	3	11	9	12.1	10	17	9	44.3	35	55
21	13	6	12	20.3	15	27	12	4.7	3	6	12	10.9	9	14	13	35.0	34	51
22	1	5	1	19.0	19	19	1	4.0	4	4	1	11.0	11	11	1	39.0	39	39
23	8	5	8	19.5	18	22	8	4.2	3	6	8	11.3	10	12	8	40.1	37	43
24	16	5	16	21.9	17	27	16	7.1	4	12	16	11.4	9	16	16	45.5	39	57
25	8	5	8	20.1	16	23	8	8.6	5	14	8	11.6	9	14	8	45.3	42	50
26	5	5	5	18.8	18	19	5	7.2	6	11	5	12.2	10	14	5	43.2	41	45
27	2	6	2	18.0	18	18	2	7.0	6	8	2	10.0	9	11	2	41.0	39	43
28	4	5	4	22.0	18	27	4	7.7	5	13	4	13.2	13	14	4	48.0	43	50
29	7	5	7	20.0	16	24	7	8.4	7	11	7	12.2	7	16	7	45.7	41	51
30	6	5	6	19.1	16	21	6	7.8	5	11	6	12.3	8	15	6	44.3	42	47
31	4	5	4	18.7	17	20	4	7.0	3	10	4	12.0	9	14	4	42.7	38	47
Aug. 1	5	5	5	18.0	17	20	5	6.4	4	9	5	13.0	11	14	5	42.4	38	45
3	2	6	2	20.0	17	23	2	4.5	2	7	2	14.0	13	15	2	44.5	44	45
5	1	5	1	19.0	19	19	1	8.0	8	8	1	13.0	13	13	1	45.0	45	45
6	7	5	7	17.7	16	21	7	5.4	2	8	7	13.8	10	16	7	42.4	38	48
11	2	5	2	17.0	17	17	2	8.5	8	9	2	12.0	12	12	2	42.5	42	43
	185	....	180	20.0	....	....	180	6.2	....	....	180	11.4	....	....	185	43.11	....	....

Total days incubation for all eggs, 952; average incubation period, 5.3 days.

THE FOURTH GENERATION.

FOURTH BROOD OF EGGS.

Time of incubation.—Egg deposition for the fourth brood of the codling moth was first found to occur on August 20, and to continue more or less regularly until September 8, thus covering a period of 19 days. From the depositions occurring in this interval a total of 125 individuals was observed and found to have an average incubation period of 7.9 days. The maximum length of the period was 10 days, and the minimum time 5 days. These records are found in Table LVII.

TABLE LVII.—*Time of incubation and length of feeding period of larvæ of the fourth brood, Roswell, N. Mex., 1913.*

Date of egg deposition.	No. individuals.	Days incubation.	Length of feeding period in specified days.																											Average days.	Minimum days.	Maximum days.	Total.
			25	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	53				
Aug. 20	4	6	...	...	2	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	32	28	36	128
21	6	6	...	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	31.3	26	42	188
22	3	6	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	25.3	25	26	76
23	4	6	1	1	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	32.7	25	40	131
24	1	5	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	36	36	36	36
25	1	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	47	47	47	47
26	1	7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	42	42	42	42
27	7	8	...	...	...	...	1	...	1	...	...	3	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1	...	44.3	30	51	266
28	10	8	...	...	...	2	...	...	...	...	1	...	4	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1	38.7	29	53	387
29	6	7	...	...	...	...	...	...	...	...	2	...	1	...	...	...	...	...	...	3	...	...	...	...	...	...	...	...	...	38.8	34	43	233
30	6	9	...	...	...	...	...	3	...	2	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	32.5	31	36	195
31	11	9	...	...	...	...	4	...	2	...	...	1	...	...	2	2	...	...	...	...	...	...	...	...	...	...	...	...	...	33.7	30	39	371
Sept. 1	16	8	...	...	...	...	...	...	...	...	...	3	...	2	2	2	1	...	2	1	...	...	1	...	1	1	...	...	...	40.2	35	49	643
2	11	8	...	...	...	...	...	...	...	...	...	...	...	1	1	2	1	...	1	2	1	...	2	...	...	...	...	...	...	41.5	37	46	457
3	17	8	...	...	...	...	...	...	...	...	...	...	...	4	...	...	1	1	1	...	3	1	1	2	...	...	3	...	...	42.8	37	50	728
4	6	8	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	...	...	1	...	3	...	...	...	45.5	39	49	273
5	4	8	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1	1	...	...	...	...	...	1	...	...	...	...	42.5	39	48	170
6	8	10	...	...	...	...	...	...	...	1	...	2	1	1	...	1	...	...	...	1	...	1	...	...	...	...	...	...	...	37.8	33	45	303
8	3	9	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...	1	...	...	...	...	...	...	...	...	40.3	35	44	121
	125	....	3	6	2	2	5	3	3	3	3	10	10	8	5	9	6	2	9	7	5	2	4	4	3	5	4	1	1	38.36	....	....	4,795

Total days incubation for all eggs, 990; average incubation period, 7.9 days.

FOURTH BROOD OF LARVÆ.

Length of feeding.—The first observation of larvæ leaving the fruit was made September 23, after a feeding period of 28 days. Records in this connection were kept with 125 individual insects and the last larvæ were found leaving the fruit on October 31, thus covering a period of 28 days. All of these individuals passed the winter as wintering larvæ.

The maximum length of the feeding period for larvæ of this generation was found to be 53 days, and the minimum period 25 days, covering a range of variation of 28 days. The average feeding period for the entire time was 38.36 days, as shown in Table LVII. This average feeding period is 17.26 days greater than the corresponding average for wintering larvæ of the third generation of this season, and 11.81 days greater than the corresponding average for all larvæ of the third generation during 1912.

MISCELLANEOUS EMERGENCE OF MOTHS.

Records of hourly observations.—In an endeavor to determine the time of day at which the greatest number of insects leave the pupal case and emerge as moths, experiments were conducted by using a number of glass jars in which larvæ collected from banded trees had been placed and on which daily emergence records were taken. The first observations of the season were made April 28, using moths of the spring brood. Observations were begun at 7 a. m. and continued throughout the day at intervals of one hour until 7 p. m. Largely because of the cool weather prevailing at that early stage of the season no emergences were found to take place until 11 a. m., when 1 moth was discovered. At 12 noon, however, 35 moths were found and at this hour a thermograph within the breeding shelter indicated a temperature of 84° Fahrenheit. At 1 p. m. a total of 14 moths was found and a temperature of 85° F. was recorded and later noted as being the highest temperature throughout the day.

On June 24 and 25 similar experiments were again conducted although no observations were made until 9 a. m., when the greatest number of accumulated moths was found for any particular hour, being 55 in all. Records show an average temperature of 70° F., for that hour on the two days. However, the highest emergence during the more heated portion of the day occurred at 3 p. m. with a total of 33 moths and an average temperature of 90° F., for that hour on the two days.

On August 1 similar records were made with emerging moths of the second generation, and the first observation of the day was made at 7 a. m., when a total of 19 moths was found. The maximum emergence of the day, however, occurred at 3 p. m., when 103 individuals were discovered. The temperature records at this hour read 83° F., while the maximum temperature of the day occurred at 12 noon and was found to be 89° F. Emergences for other hours throughout the day on which records were taken were found to be in varying numbers, as is shown in Table LVIII. Of a total of 731 records of individual emergences, 137 occurred at 3 p. m. which, according to these records, can be considered the hour of maximum emergence.

TABLE LVIII.—*Records of hourly emergence of codling moths of the spring brood, and of the first and second broods, Roswell, N. Mex., 1913.*

Date of observation.	Hour of day.													Total emergence
	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.	6 p. m.	7 p. m.	
Spring brood:														
Apr. 28	......	......	......	......	1	35	14	4	1	3	1	......	......	59
First brood:														
June 24	......	......	7	......	......	......	2	1	2	......	......	......	......	10
24	......	......	1	......	......	......	......	......	......	......	......	......	......	1
24	......	......	21	2	4	4	4	5	3	......	......	......	......	43
24	......	......	......	31	6	10	8	13	17	5	7	3	2	102
24	......	......	......	......	......	......	......	5	......	......	1	......	......	6
25	......	......	......	......	......	......	......	......	......	2	......	......	......	2
25	......	......	2	1	2	1	1	1	......	......	......	1	......	9
25	......	......	21	9	18	10	9	3	8	3	2	......	......	83
25	......	......	3	1	2	1	......	1	4	1	......	......	......	13
25	......	......	......	......	......	......	1	......	1	1	......	......	1	4
	......	......	55	44	32	26	25	29	33	12	10	4	3	273
Second brood:														
Aug. 1	13	3	6	3	3	5	4	14	40	29	24	5	2	151
1	6	1	6	4	5	4	9	24	63	40	58	21	7	248
	19	4	12	7	8	9	13	38	103	69	82	26	9	399
Total	19	4	67	51	41	70	52	71	137	84	93	30	12	731

BAND RECORDS OF 1913.

Band records were regarded as forming an important part of the life-history studies conducted throughout the season.

Besides the advantage offered in the opportunity to study the insect under natural conditions, the careful collection of accumulated larvæ from the bands at regular intervals serves to furnish valuable data on the relative abundance of the several broods of larvæ throughout the season, and provides in addition desirable material for laboratory rearing experiments.

During the season of 1913, band records were conducted at different points within the State in an endeavor to secure possible data on the life history and habits of the insect in more or less widely-separated localities which represented a variety of conditions.

In addition to the band-record experiments at Roswell, similar experiments were installed at Carlsbad, Artesia, Lincoln, and Santa Fe. At Carlsbad some difficulty was experienced in finding suitable trees for banding because of the scarcity of desirable trees of bearing age. Carlsbad and vicinity may be considered to represent one of the points of lowest altitude in New Mexico, and largely for this reason it was desired to install experiments there. Through the courtesy of Mr. Francis G. Tracy, however, five apple trees were set aside for this purpose.

No larvæ were reported found during May and only a total of 21 larvæ throughout the month of June. Partly on account of the prevailing scarcity of fruit on the trees used, no collections were made after July 1, and later the work in this locality was abandoned.

RESULTS AT ROSWELL.

Banded trees for the experiments at Roswell were selected about May 15, although no collections are recorded until May 20. Through the kindness of a number of orchard owners, trees for banding were obtained as follows: Five trees on the farm of Capt. W. C. Reid, 5 belonging to Mr. H. J. Hagerman; 4 in the orchard of Mr. R. C. Horner; and 3 in an orchard owned by Mr. Robert Beers. Careful collections were made from the bands on these trees at intervals of three days from May 20 until November 7, and an accurate record kept of the larvæ found. By consulting the figures in Table LIX it will be noted that the maximum number of first-brood larvæ occurring in the field is found to be on May 29, when 833 larvæ were

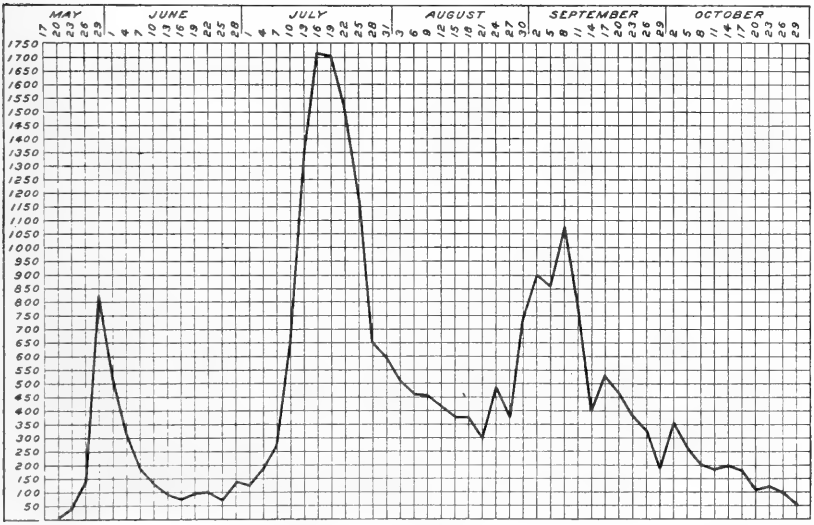

FIG. 11.—Curve showing occurrence of codling-moth larvæ under bands on apple trees, Roswell, N. Mex., 1913. (Original.)

collected from the 17 banded trees. Of this number, 129 proved to be wintering larvæ while 654 transformed and emerged as moths.

A second maximum is found to occur July 16, when 1,674 larvæ were collected from the bands. Of this number 339 proved to be wintering larvæ, and 1,318 transformed the same season.

The greatest number of third-brood larvæ collected on a specified date occurred September 8, when 1,073 are recorded. The number of larvæ wintering at this time in the season is much greater, a total of 1,062 being found, while only 3 larvæ transformed and emerged the same season. Because of the overlapping of the broods of larvæ late in the season, this condition renders it impossible to determine from these data when fourth-brood larvæ occurred in greatest numbers in the field. (See fig. 11.)

TABLE LIX.—*Codling-moth larvæ from bands and emergence of moths, Roswell, N. Mex., 1913.*

Observation No.	Date of collection.	Number of larvæ.	Emergence of moths.	Number of wintering larvæ.	Observation No.	Date of collection.	Number of larvæ.	Emergence of moths.	Number of wintering larvæ.
1	May 20	5	3	1	30	15	375	118	255
2	23	40	39	1	31	18	367	110	253
3	26	140	139	1	32	21	295	82	213
4	29	833	654	129	33	24	484	67	412
5	June 1	517	463	54	34	27	378	19	357
6	4	320	274	46	35	30	730	11	719
7	7	249	150	99	36	Sept. 2	900	4	896
8	10	130	113	17	37	5	858	....	858
9	13	89	82	7	38	8	1,073	3	1,062
10	16	76	70	6	39	11	815	....	805
11	19	95	77	18	40	14	395	....	386
12	22	94	88	6	41	17	533	1	527
13	25	69	68	1	42	20	465	....	465
14	28	140	128	11	43	23	381	....	381
15	July 1	127	112	14	44	26	330	....	330
16	4	183	153	30	45	29	174	....	174
17	7	274	251	22	46	Oct. 2	354	....	354
18	10	654	548	94	47	5	265	....	265
19	13	1,335	1,060	275	48	8	205	....	205
20	16	1,674	1,318	339	49	11	182	....	182
21	19	1,667	1,324	350	50	14	192	....	192
22	22	1,510	1,258	248	51	17	180	....	180
23	25	1,166	969	197	52	20	107	....	107
24	28	652	548	99	53	23	119	....	119
25	31	618	434	176	54	26	100	....	100
26	Aug. 3	510	300	206	55	29	51	....	51
27	6	463	238	223	56	Nov. 1	....	....	....
28	9	458	174	284	57	4	....	....	....
29	12	432	154	277	58	7	65	....	65

RESULTS AT ARTESIA.

The results from the band records at Artesia proved much more satisfactory than did those at Carlsbad, and some valuable data were obtained.

The experiments were installed somewhat later in the season than were those at Roswell, and in consequence the first collection of larvæ was not made until June 4, on which date 33 larvæ were found. This date may be considered too late in the season to serve in determining the occurrence at this place of the maximum number of first-brood larvæ to contrast with May 29, the date when the greatest number occurred at Roswell.

On July 10, however, 719 larvæ were taken from the bands and represent the maximum number for second-brood larvæ. This occurred just six days earlier in the season than did the corresponding stage at Roswell.

From the figures at hand relative to the greatest number of larvæ to be found in the field at the time of the first collection in September, no maximum number can be described, but from previous conclusions drawn from contrasts with corresponding stages at Roswell, it would appear that the greatest number of third-brood larvæ would be found about September 2.

Regular collections were made on specified dates throughout the season corresponding with the collections made at Roswell and continuing until September 17, when the records were discontinued. The records of these collections are more fully shown in Table LX.

TABLE LX.—*Band records at Artesia, N. Mex., 1913.*

[Larvæ collected by Mr. N. E. Brainard.]

Record No.	Date of collection.	Number of larvæ.	Emergence of moth.	Wintering larvæ.	Record No.	Date of collection.	Number of larvæ.	Emergence of moth.	Wintering larvæ.
6	June 4	33	20	13	24	28	284	194	90
7	7	50	27	23	25	31	179	128	51
8	10	24	21	3	26	Aug. 3	123	72	51
9	13	10	8	2	27	6	113	35	78
10	16	48	31	17	28	9	55	27	28
11	19	44	39	5	29	12	56	19	37
12	22	43	30	13	30	15	73	28	45
13	25	61	42	19	31	18	42	16	26
14	28	119	56	63	32	21	50	9	43
15	July 1	99	66	33	33	24	47	2	45
16	4	345	181	164	34	27	29	3	26
17	7	542	293	249	35	30	21	....	21
18	10	719	530	189	36	Sept. 2	19	....	19
19	13	643	406	237	37	5	24	....	24
20	16	570	431	139	38	8	10	....	10
21	19	423	342	81	39	11	14	....	14
22	22	278	207	61	40	14	3	....	3
23	25	420	261	159	41	17	7	....	7

Figure 12 represents graphically the results of band records at Artesia, and in addition shows the probable time of occurrence in

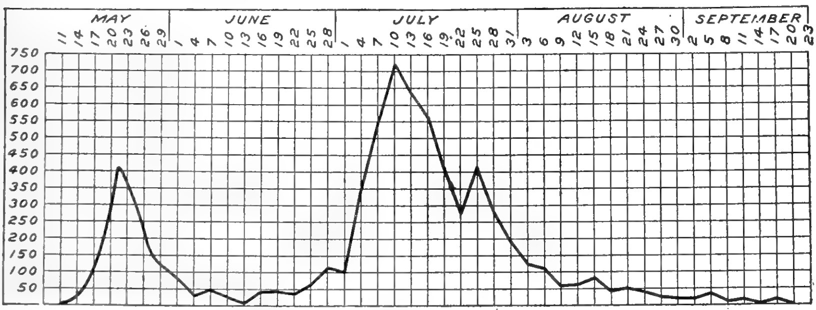

FIG. 12.—Curve showing codling-moth larvæ under bands on apple trees, Artesia, N. Mex., 1913. (Original.)

the field of larvæ of the first brood. While this feature is of a more or less speculative nature, it may be regarded as being in close accordance with facts.

RESULTS AT LINCOLN.

Lincoln is located 65 miles west of Roswell, between El Capitan Mountain and Sierra Blanca peak, a northerly spur of the Sacramento Mountains, and has an altitude of some 5,700 feet. Through the courtesy of Dr. J. W. Laws a number of bearing apple trees were set aside for use in banding, and these furnished larvæ throughout the season. While the bands were placed on the trees early in May, no larvæ were found until June 13. Despite the fact that larvæ occurred more or less intermittently from that date until the season closed, November 7, it would appear that only two full broods and a partial third are found in the higher fruit-growing regions.

The records found in Table LXI show that the maximum number of larvæ of the first brood of that season were found beneath the bands July 13. The greatest number of second-brood larvæ occurred August 30, 48 days later, and the very probable overlapping of this brood with larvæ of the partial third brood, coupled with a decreasing amount of available fruit during the late summer and early fall,

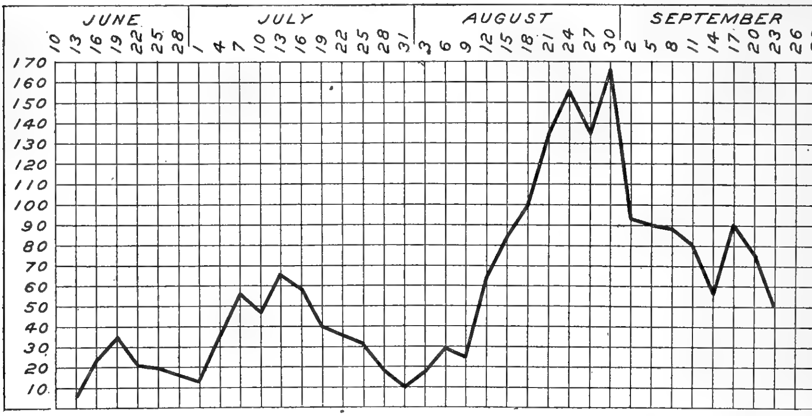

FIG. 13.—Curve showing occurrence of codling-moth larvæ under bands on apple trees, Lincoln, N. Mex., 1913. (Original.)

undoubtedly was influential in producing a uniform number of larvæ from which no reliable maximum number could be determined.

TABLE LXI.—*Codling-moth larvæ from bands and emergence of moths, Lincoln, N. Mex., 1913.*

[Larvæ collected by Mr. E. A. Engstrom.]

Record No.	Date of collection.	Number of larvæ.	Emergence of moths.	Number of wintering larvæ.	Record No.	Date of collection.	Number of larvæ.	Emergence of moths.	Number of wintering larvæ.
1	May 20	....	....	....	30	Aug. 15	84	35	49
2	23	....	....	....	31	18	100	26	74
3	26	....	....	....	32	21	134	24	110
4	29	....	....	....	33	24	156	6	150
5	June 1	....	....	....	34	27	134	2	132
6	4	....	....	....	35	30	167	1	166
7	7	....	....	....	36	Sept. 2	93	....	93
8	10	....	....	....	37	5	89	....	89
9	13	7	6	1	38	8	88	1	87
10	16	25	18	7	39	11	71	....	71
11	19	35	29	6	40	14	56	....	56
12	22	20	13	7	41	17	89	....	89
13	25	20	18	2	42	20	78	....	78
14	28	17	14	3	43	23	50	....	50
15	July 1	14	14	....	44	26	34	....	34
16	4	36	31	5	45	29	20	....	20
17	7	56	42	10	46	Oct. 2	28	....	28
18	10	46	40	6	47	5	30	....	30
19	13	67	50	17	48	8	26	....	26
20	16	60	50	10	49	11	32	....	32
21	19	41	24	17	50	14	40	....	40
22	22	37	31	6	51	17	29	....	29
23	25	32	23	9	52	20	12	....	12
24	28	17	12	5	53	23	7	....	7
25	31	10	8	2	54	26	23	....	23
26	Aug. 3	17	9	8	55	29	1	....	1
27	6	30	20	10	56	Nov. 1	6	....	6
28	9	25	11	14	57	4	14	....	14
29	12	61	22	39	58	7	15	....	15

The band-record curve found in figure 13 is intended to show in a general way the fluctuating occurrence of larvæ in the region of Lincoln, and in addition to illustrate the periods when greatest numbers of larvæ may probably be present.

While the figures in Table LXI give the number of moths emerging from each specific collection, no dates corresponding to these emergences are included. Reference to figure 14 will, however, furnish data showing the number of moths emerging on specified days from June 26 until September 20, after which date the adults failed to appear. The somewhat exceptional fluctuating feature of the emergences is here graphically illustrated.

RESULTS AT SANTA FE.

Santa Fe is located somewhat north of the geographical center of New Mexico, at an altitude of about 7,000 feet. While commercial fruit growing has never been conducted here on as extensive a scale as in many other parts of the State, the section has long been settled and the growing of fruit has been practiced

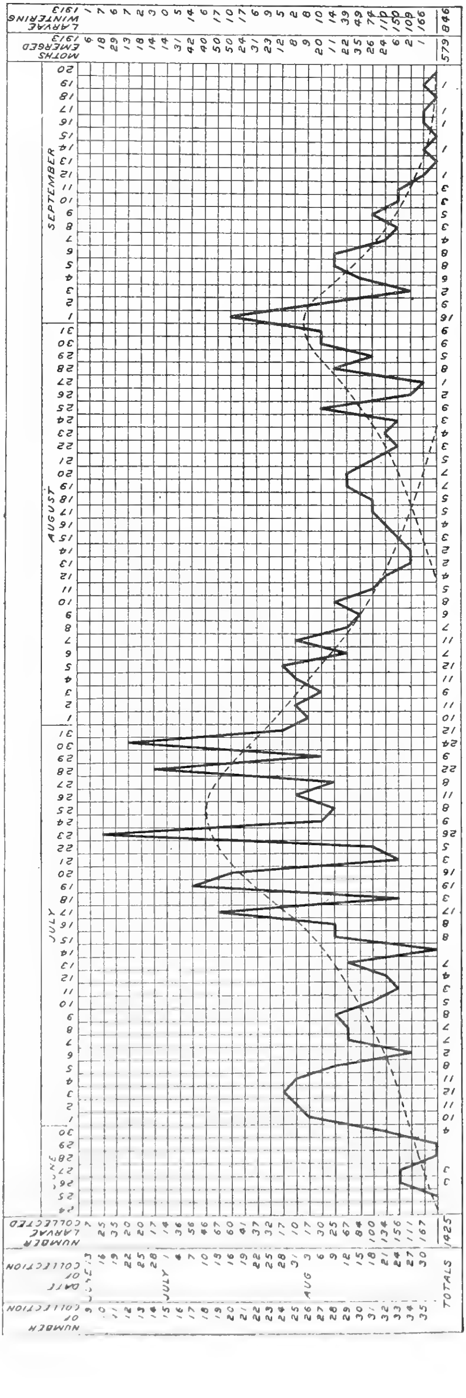

FIG. 14.—Curve showing emergence of codling moths from band-record larvæ at Lincoln, N. Mex., 1913. (Original.)

for many years. Because of the rather exceptionally high altitude and its possible effect on insect behavior, it was considered desirable to make band records in this mountain locality.

Through the courtesy of Dr. James Rolls, a number of trees were obtained for this purpose, and bands placed on them in May. However, no larvæ were found until June 7, when 5 were taken from the bands, 4 of which proved to be wintering larvæ. The maximum number of larvæ of the first brood occurred July 16, the exact date of the occurrence of the greatest number of larvæ of the second brood at Roswell. From this date on the number collected is so variable that no very definite conclusions can be drawn. However, it appears probable that the overlapping of first-brood larvæ with a partial second brood may have taken place about September 5. Reference to Table LXII will show the great number of wintering larvæ after August 1 and the number of moths emerging from band-record larvæ throughout the season.

TABLE LXII.—*Band records for the codling moth at Santa Fe, N. Mex., 1913.*

[Larvæ collected by Mr. Alfred Rolls.]

Record No.	Date of collection.	Number of larvæ.	Emergence of moths.	Wintering larvæ.	Record No.	Date of collection.	Number of larvæ.	Emergence of moths.	Wintering larvæ.
7	June 7	5	1	4	33	Aug. 24	15	....	15
8	10	....	....	....	34	27	26	....	26
9	13	....	....	....	35	30	19	....	19
10	16	1	....	1	36	Sept. 2	20	....	20
11	19	2	....	2	37	5	22	....	22
12	22	4	2	2	38	8	16	....	16
13	25	....	....	....	39	11	11	....	11
14	28	2	....	2	40	14	7	....	7
15	July 1	....	....	....	41	17	6	....	6
16	4	1	....	1	42	20	17	....	17
17	7	3	3	....	43	23	9	....	9
18	10	10	8	2	44	26	....	....	....
19	13	21	12	9	45	29	4	....	4
20	16	38	28	10	46	Oct. 2	13	....	13
21	19	23	14	9	47	5	7	....	7
22	22	24	7	17	48	8	12	....	12
23	25	28	8	20	49	11	11	....	11
24	28	19	4	15	50	14	8	....	8
25	31	25	....	25	51	17	8	....	8
26	Aug. 3	19	....	19	52	20	6	....	6
27	6	35	1	....	53	23	6	....	6
28	9	34	....	....	54	26	....	....	....
29	12	37	....	37	55	29	....	....	....
30	15	25	....	25	56	Nov. 1	....	....	....
31	18	36	....	36	57	4	....	....	....
32	21	31	....	31	58	7	1	....	1

In figure 15 may be seen a diagram illustrating the variable manner in which the larvæ were found to occur in the field at Santa Fe during the season of 1913. While it is difficult to account for this evident variation, weather conditions prevailing at times during the period of observations very probably influenced the number of larvæ materially.

The emergence of moths from band-record larvæ at Santa Fe was more or less regular, according to the curve found in figure 16, as contrasted with the corresponding illustration dealing with the emergence of moths from band-record larvæ collected at Lincoln the same season. From a total of 260 larvæ removed from the bands at Santa Fe, 169 larvæ, or 65 per cent, proved to be wintering larvæ, and 88 of the entire number transformed the same season to emerge as moths.

SEASONAL HISTORY OF THE CODLING MOTH DURING 1913.

Figure 17 illustrates graphically the seasonal history of the codling moth during 1913 with dates of the respective broods and genera-

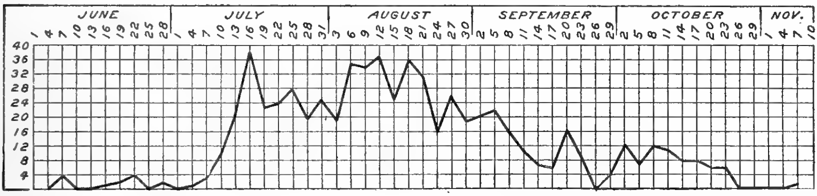

FIG. 15.—Curve showing occurrence of codling-moth larvæ under bands on apple trees, Santa Fe, N. Mex., 1913. (Original.)

tions. As in the case of figure 4, illustrating the seasonal history for 1912, the periods indicated by these diagrams are averaged or generalized, and the tables giving actual dates of occurrence should be consulted when specific information is wanted. Both of the seasonal-history charts are made on the same plan and the description of figure 4 on pages 31–32 will apply alike to both of the illustrations.

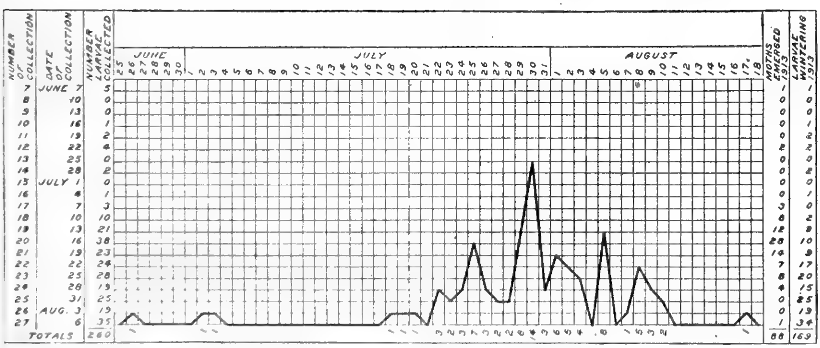

FIG. 16.—Curve showing occurrence of codling-moth larvæ under bands on apple trees, Santa Fe, N. Mex., 1913. (Original.)

SUMMARY.

In the Pecos Valley of New Mexico the codling moth produced during 1912 three complete generations. In 1913 a partial fourth brood of larvæ developed, and it is considered probable that this is of normal occurrence.

Pupation of overwintering larvæ in 1912 began March 15 and continued for about one month. In 1913 the first pupa was noticed March 23 and pupation continued for 51 days.

Moths of the spring brood in 1912 were first in evidence April 12 and continued to emerge to May 28. In 1913 the spring brood of moths was out from April to early June.

Female moths of the spring brood in 1912 lived on the average 8.47 days and in 1913, 12.88 days. Male moths in 1912 lived 6.7 days.

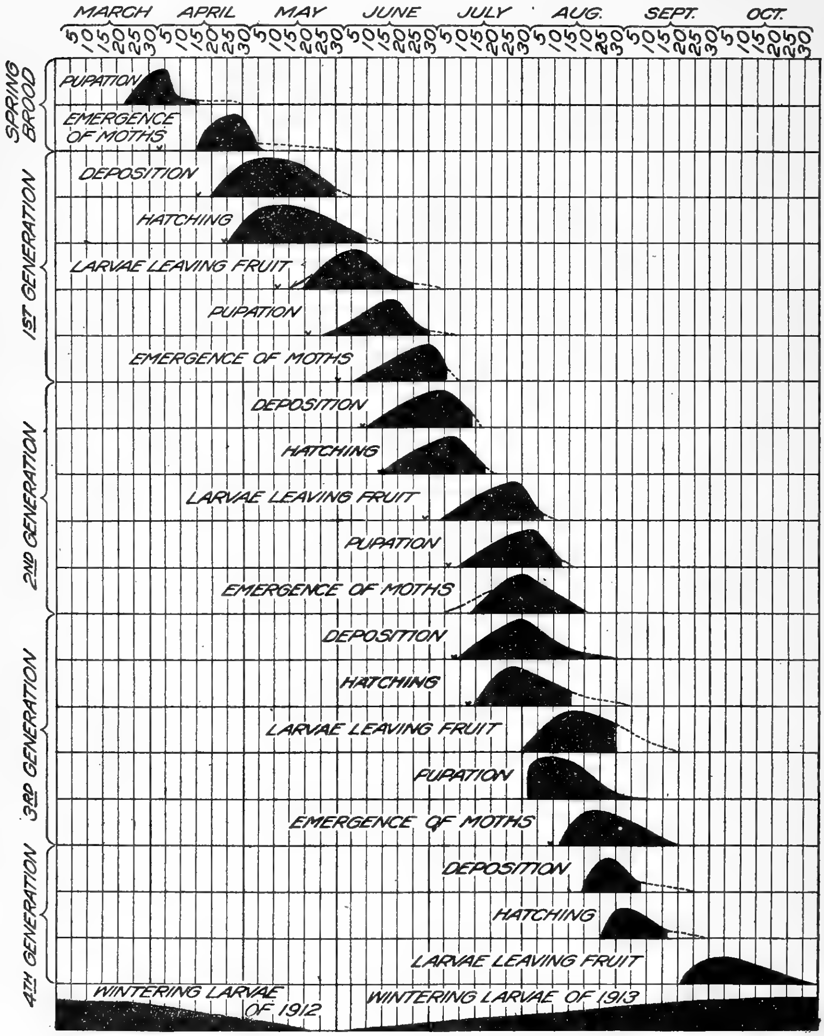

FIG. 17.—Diagram showing the seasonal history of the codling moth at Roswell, N. Mex., in 1913. (Original.)

In 1912 oviposition of the spring brood of moths began April 16, continuing 45 days, while in 1913 first eggs of this brood were noted May 1. The time required for first-brood eggs to hatch in 1912 was 9.05 days, with a range of 5 to 13 days, whereas in 1913 eggs of this brood hatched on an average in 5.96 days, with a range of from 4 to 11 days.

First-brood larvæ in 1912 fed on an average 21.52 days, and in 1913, 24.45 days.

The pupal stage of the first brood in 1912 averaged 12 days, and in 1913, 11 days.

Moths of the first brood in 1912 were out June 9 and continued to emerge until July 22. In 1913 first moths were out June 3, the period of emergence lasting until July 10.

First-brood moths in 1912 oviposited over an average period of 4.45 days, and in 1913, 5.7.

The life cycle of the first generation in 1912 required on the average 51.14 days, and in 1913, 46.91 days.

Second-brood eggs in 1912 averaged 5.62 days for incubation, with a minimum of 4, and a maximum of 8 days. The incubation period of eggs of this brood in 1913 was on the average 4.9, with a minimum of 4 and a maximum of 7 days.

The feeding period of second-brood larvæ in 1912 averaged 21.23 days, and in 1913, 19.7 days.

The pupal stage for second-brood pupæ in 1912 averaged 11.23 days, and in 1913, 11.06 days.

The life cycle for the second generation of the codling moth in 1912 averaged 41.26 days, and in 1913, 41.04 days.

Eggs of the third brood in 1912 averaged 5.75 days for the incubation period, with a minimum of 4 and a maximum of 9 days. In 1913 the incubation period for eggs of this brood averaged 5.36 days.

During 1912 third-brood larvæ fed on an average of 26.55 days with a range of from 15 to 56 days, whereas in 1913 the average feeding period for this brood was 20 days, the range being from 15 to 28 days.

The pupal stage of the third brood in 1912 required on an average 14.94 days, with a minimum of 11 and a maximum of 20 days. The average length of this stage in 1913 was 11.4 days, with a minimum of 7 and a maximum of 17 days.

The life cycle of the third generation of 1912 required on an average 48.57 days, with a range of from 36 to 62 days, and in 1912, 43 days, with a range of 34 to 58 days.

Fourth-brood eggs were in evidence in 1913 on August 20, and oviposition continued to September 8. The incubation period, on an average, was 7.9 days.

The feeding period of fourth-brood larvæ in 1913 averaged 38.36 days, with a minimum of 25 days and a maximum of 53 days. All of these larvæ passed the winter as such.

Records of egg deposition by individual moths were obtained with females of the spring brood and also of the first and second broods. The maximum egg deposition by a female of the spring brood in 1912 was 91 eggs, while the average number per moth was approximately 28 eggs.

The highest oviposition record established was by a female of the second brood in 1913, with a total of 259 eggs.

Oviposition may occur two days after the emergence of moths, and, on an average, moths of the first brood in 1913 continued oviposition over a period of 5.7 days.

The average incubation period for all eggs of the four generations produced during 1913 was 6.4 days. The corresponding average for the three generations during the season of 1912 was 6.8 days.

Studies in the insectary of the hourly emergence of moths show that of 788 records of individuals the greatest number, 17.44 per per cent, emerged at 3 p. m. In general the maximum period of emergence was found to occur at the time of, or almost immediately following, the period of highest temperature for the day. There was some variation from this, however, earlier in the season.

Fourth-brood larvæ were found leaving the fruit on September 23, after a feeding period of 28 days. Larvæ of this brood persisted as late as October 21 in the rearing shelter, and the last collection from bands in orchards showed larvæ to be present as late as November 1.

The wintering larvæ of 1913, as illustrated in figure 17, were composed of 7.16 per cent of the larvæ of the first brood; of 19.98 per cent of the larvæ of the second brood; of 75.06 per cent of larvæ of the third brood; and of 100 per cent of the fourth brood.

The feeding period of wintering larvæ of the first brood in 1913 was 0.68 day longer than the corresponding period for the transforming larvæ of the same brood. Wintering larvæ of the second brood fed 1.94 days longer than transforming larvæ of this brood, while the length of feeding period of wintering larvæ of the third brood exceeded that of the transforming larvæ by 1.1 days.

The probable effect of sudden changes of temperature on the activities of the codling moth is illustrated in figure 8. Temperature records also accompany figure 1.

Successful band records were made during 1913 at Roswell, Artesia, Lincoln, and Santa Fe. From available data the conclusion is drawn that at Lincoln there occur two full generations and a partial third, while at Santa Fe, a more northerly location, there appears to be but one complete generation, followed by a partial second.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 430

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ October 28, 1916

CEREAL EXPERIMENTS ON THE CHEYENNE EXPERIMENT FARM, ARCHER, WYO.

By JENKIN W. JONES, *Scientific Assistant, Office of Cereal Investigations.*

[In cooperation with the Wyoming State Board of Farm Commissioners.]

CONTENTS.

	Page.
Introduction	1
Description of the district	2
Cheyenne Experiment Farm	8
Experiments with wheat	12
Experiments with emmer and spelt	25
Experiments with oats	26
Experiments with barley	30
Experiments with flax	33
Experiments with minor grain crops	36
Summary	38

INTRODUCTION.

The cooperative experiments conducted on the Cheyenne Experiment Farm, Archer, Wyo., were started in 1912.[1] Three years' results of the work are now available. It is realized that three years in a dry-farming district is too short a period to warrant the drawing of conclusions. However, the demand for available facts is very strong and these data should be interesting and helpful to those engaged in dry farming in the higher parts of the northern Plains area. Therefore, it seems advisable at this time to present the results thus far obtained.

Cooperation between the Bureau of Plant Industry and the Wyoming Board of Farm Commissioners was effected on July 1, 1912. According to the memorandum of understanding between the two parties—

> The objects of these cooperative investigations shall be (*a*) to improve the cereals of the northern Plains area by introducing or breeding better varieties than those now grown, with special reference to earliness, drought resistance, winter hardiness, quality, yield, etc.; and (*b*) to determine the best methods of cereal production under dry-land conditions in the area named.

[1] The writer was superintendent of the Cheyenne Experiment Farm from September 1, 1912, until April 30, 1915, when he returned to the Nephi substation, in Utah. Mr. Victor H. Florell was appointed scientific assistant in cereal investigations and superintendent of the experiment farm on April 20, 1915, and was in charge during the cropping season of 1915. Credit is hereby given him for the results obtained in that year.

The results obtained at Archer are applicable to a greater or less extent to northeastern Colorado, western Nebraska, a narrow portion of western South Dakota, and to eastern Wyoming. However, the climatic conditions in any particular locality should be compared carefully with those obtaining at Archer before the data are too widely applied. The elevation at Archer is as great and the climatic conditions probably are as severe as in the other districts mentioned, so that the results should be quite generally applicable.

This bulletin contains (1) a description of the district to which the results apply, (2) a description of the Cheyenne Experiment Farm and the scope and method of the experiments conducted there, and (3) the results of these experiments with different field crops and cropping methods.

DESCRIPTION OF THE DISTRICT.

The district here described includes the plains of southeastern Wyoming, western Nebraska, and northeastern Colorado. The results presented in this bulletin are believed to be generally applicable to this district.

HISTORY.

The district was first used for stock grazing. It was the home of ranchmen who owned or leased large areas of land. The ranches were located on streams or springs, in order to have water available for stock during the summer months.

When Wyoming was admitted as a State in 1890, 4,042,160 acres were granted by Congress for educational and other public purposes. By a provision in a law approved in 1891 no State lands could be sold at less than $10 per acre. As a result of this law, up to 1902 only a little over 5,000 acres of State land had been sold. Meantime numerous provisions had been enacted for leasing the State lands in order to secure some revenue from them. Leasing prices ranged from 2½ to 25 cents per acre annually, the price depending on whether the land was accessible to water for stock or for irrigation. The land leased readily and ranchmen became prosperous. The high sale price of State lands and the large area leased, including practically all the natural watering places, have operated to keep out the small dry-land farmer. The opposition of the ranchmen to general farming is another factor that has retarded cereal production in Wyoming.

As the population increased and land prices became higher in the Central States large numbers of people have continued to move westward. This western migration, which has been especially marked during the past decade, has resulted in the settlement or homesteading of large areas of the higher Plains region, formerly used for grazing.

The new settlers on these lands for the most part come from the Central States. They come into an area that requires farming methods different from those to which they are accustomed. They are confronted by numerous and varied problems of crop adaptation and production which are entirely new to them. Reliable information on crops and farm practices is seriously needed.

TOPOGRAPHY.

The district outlined above lies to the east of the foothills of the Rocky Mountains, at an elevation ranging from 5,000 to 6,000 feet. The land is gently rolling. It slopes eastward from the foothills to about 102° W. longitude, which may be called the eastern boundary of the higher western Plains area. In this district the summers are short and only short-season crops will mature.

SOILS.

The soils of the district are of varying types, ranging from light sandy loam to a very heavy impervious clay loam. They are underlain with gravel at some points and with hardpan at others. The humus content of the soil generally is low over the entire district. The soil in many localities is very light and subject to drifting, while in other localities it is very heavy and difficult to work. In general, however, the soil is fairly easy to work and is rich in plant food elements. While it is low in humus content, crop yields are usually good when the moisture supply is not too limited.

VEGETATION.

The native grass vegetation of southeastern Wyoming consists largely of buffalo grass (*Bulbilis dactyloides*), blue grama (*Bouteloua oligostachya*), western wheat-grass (*Agropyron smithii*, formerly *A. occidentale*), and little bluestem (*Andropogon scoparius*). These are common grasses of much of the Great Plains area. They are drought resistant, nutritious, and well suited for grazing purposes.

The most abundant native legumes are *Thermopsis divaricarpa*, milk vetch (*Astragalus adsurgens* and *A. bisulcatus*), narrow-leaved vetch (*Vicia linearis*), and lupine (*Lupinus pusillus*). Some vetches and lupines when green are considered poisonous to animals, but are not believed to be poisonous when cured.

Russian thistle (*Salsola tragus*), Canada thistle (*Carduus arvensis*), yellow mustard (*Brassica* and *Sisymbrium* spp.), and tumbleweeds (*Amaranthus* spp.) are among the most common weeds, particularly on land where the native sod has been broken.

CLIMATE.

There are at least three distinct climatic factors that influence directly or indirectly the yields of crops in semiarid regions. These are (1) precipitation, particularly the distribution of the rainfall; (2)

wind, particularly that which passes directly over the ground during the crop season; and (3) temperature, with special reference to the length of the frost-free period in a given locality.

PRECIPITATION.

Rainfall is undoubtedly the most important factor in crop production in southeastern Wyoming. Table I shows the monthly, seasonal (April to July), and annual precipitation at Cheyenne, Wyo., in the 16-year period, 1900 to 1915, inclusive. The seasonal and annual precipitation are shown graphically in figure 1.

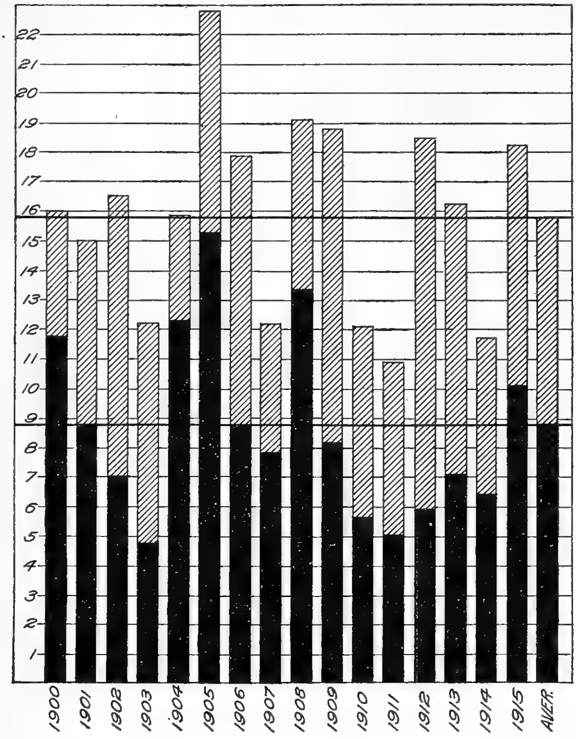

FIG. 1.—Diagram showing the seasonal and the annual precipitation (in inches) at Cheyenne, Wyo., for 16 years, 1900 to 1915, inclusive.

Table I shows that the highest monthly precipitation during the 16-year period was 7.66 inches, in April, 1900. The lowest monthly precipitation during that period was a trace, in November, 1901. The highest seasonal (April to July) precipitation recorded during the 16 years was 15.36 inches, in 1905. The lowest seasonal precipitation was 4.77 inches, recorded in 1903. The average seasonal precipitation was 8.59 inches.

The highest annual precipitation recorded during the 16-year period was 22.68 inches, in 1905. The lowest annual precipitation during the same period was 10.85 inches, in 1911. The average annual precipitation for the 16 years was 15.78 inches.

The monthly precipitation varies widely from year to year. Marked variations are observed also in the seasonal and annual precipitation of the different years.

The growing season, or the period during which spring cereals make most of their growth, covers the four months from April to July, inclusive. It is the rainfall during these four months that is of most vital concern in crop growth. Most crop failures other than those caused by factors of limited duration, such as hot wind, frost, or hail, are due to the insufficiency or poor distribution of the moisture during these months. According to the data recorded in Table I for the 16 years, 1900 to 1915, about 54 per cent of the annual precipitation comes between April 1 and July 31, the period of most active crop growth.

TABLE I.—*Monthly, seasonal (April to July), and annual precipitation at Cheyenne, Wyo., for the 16-year period, 1900 to 1915, inclusive.*

[Data (in inches) from the records of the United States Weather Bureau except as noted.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal.	Annual.
1900	0.15	1.25	0.72	7.66	0.76	1.01	1.20	0.70	2.19	0.03	0.09	0.33	10.63	16.09
1901	.13	1.10	1.54	2.97	2.47	1.93	1.34	.83	.75	.31	[a]T	1.62	8.71	14.99
1902	.21	.55	2.11	1.49	2.51	1.55	1.49	.53	3.52	.52	.23	1.79	7.04	16.50
1903	.20	1.76	1.00	2.10	.46	1.42	.79	1.90	1.40	.34	.79	.09	4.77	12.25
1904	.35	.33	.45	1.80	6.66	1.78	2.00	.87	.83	.57	.02	.06	12.24	15.72
1905	.84	.69	1.27	6.45	4.04	1.90	2.97	1.93	1.06	1.40	.11	.02	15.36	22.68
1906	.21	.21	2.27	3.10	1.30	2.42	1.89	.49	1.86	2.33	1.42	.15	8.73	17.65
1907	.42	.49	.49	1.32	2.78	.34	3.50	.80	92	.08	.59	.55	7.94	12.34
1908	.36	.20	.16	.36	6.19	2.52	4.33	2.45	.09	1.14	.59	.70	13.40	19.09
1909	.33	1.42	3.22	.97	2.15	4.01	1.08	1.40	1.37	.28	.73	.66	8.21	17.62
1910	.29	.31	1.45	1.14	2.34	.76	1.32	.62	1.80	1.04	.29	.69	5.56	12.05
1911	.49	.56	.16	1.93	.33	1.64	1.21	1.35	1.35	.95	.59	.29	5.11	10.85
1912	.44	1.60	1.33	1.62	1.37	1.17	1.82	1.44	3.91	2.59	.58	.63	5.98	18.50
1913	.55	.74	.33	1.35	2.22	[b]1.51	[b]2.06	[b]2.09	[b]2.23	1.43	.37	2.00	7.14	16.28
1914	.10	.23	.72	[b]2.54	[b]1.46	[b]1.12	[b]1.43	[b]2.03	[b].32	1.29	.26	.16	6.55	11.66
1915	.08	.49	.71	[b]4.90	[b]1.78	[b]1.83	[b]1.65	[b]2.53	[b]1.95	[b]1.81	[b].03	[b].56	10.16	18.32
Average	.32	.75	1.12	2.61	2.43	1.68	1.88	1.37	1.60	1.01	.42	.64	8.59	15.78
Maximum	.84	1.76	3.22	7.66	6.66	4.01	4.33	2.53	3.91	2.59	1.42	2.00	15.36	22.68
Minimum	.08	.20	.16	.36	.33	.34	.79	.49	.09	.03	T	.02	4.77	10.85

[a] T=trace.
[b] Data obtained at the Cheyenne Experiment Farm by the Office of Biophysical Investigations of the Bureau of Plant Industry.

EVAPORATION.

Second to precipitation in importance is evaporation, especially that which occurs during the growing season. Table II shows the monthly evaporation and precipitation at Archer for the four months of this season in each of the three years 1913, 1914, and 1915. The evaporation here recorded is from a free water surface. June and July are the months of highest evaporation at Archer. The total evaporation for the four months varies considerably, ranging from 20 inches in 1915 to 25.58 inches in 1914.

The ratio of precipitation to evaporation during the growing season in 1913 to 1915, inclusive, is interesting and instructive. The data show that the ratio varies widely in the different years. The higher the precipitation, the nearer the ratio approaches equality and the higher the crop yields. Low evaporation is associated with high yields, provided the rainfall is normal. The evaporation during

April is naturally much lower than that during the warmer months. In the only year in which a good crop was obtained, the precipitation was high and the evaporation low, making a ratio of 1:2.

TABLE II.—*Monthly and total precipitation and evaporation from a free water surface at the Cheyenne Experiment Farm, Archer, Wyo., in the months of April to July, inclusive, for 1913, 1914, and 1915.*

[Data (in inches) obtained by the Office of Biophysical Investigations of the Bureau of Plant Industry, except as noted.]

Year.	April.		May.		June.		July.		Total.		Ratio, precipitation to evaporation.
	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	
1913	[a]1.35	[b]3.217	[a]2.22	[b]5.304	1.51	7.104	2.06	7.756	7.14	23.381	1:3.27
1914	2.54	3.574	1.46	5.703	1.12	8.317	1.43	7.987	6.55	25.581	1:3.91
1915	4.90	3.160	1.78	4.701	1.83	5.557	1.65	6.638	10.16	20.056	1:1.97

[a] Data from United States Weather Bureau at Cheyenne, Wyo. [b] Interpolated.

WIND.

Wind velocities have been recorded at Cheyenne during a long series of years. The average wind velocity in miles per hour, by months, from April to July of each year, in the 16-year period from 1900 to 1915, inclusive, is given in Table III. Strong winds are quite common in southeastern Wyoming, and crops are damaged at times by the drifting soil. The highest velocities are recorded during the late fall and winter months. April has the highest average hourly velocity for the months under discussion, 11.2 miles, and July the lowest, 8.5 miles, per hour. The anemometer was located at a height of 64 feet above the ground. These readings, therefore, probably are higher than they would have been if the anemometer had been located just above the surface. Evaporation usually increases with wind velocity. In the winter months the snowfall is, as a rule, blown to the lower levels, leaving the winter crops exposed. For this reason winter-killing of fall-sown crops is common.

TABLE III.—*Average wind velocity at Cheyenne, Wyo., by months, from April to July of each year, during the 16-year period, from 1900 to 1915, inclusive.*

[Data (in miles per hour) from the records of the United States Weather Bureau.]

Year.	April.	May.	June.	July.	Average.	Year.	April.	May.	June.	July.	Average.
1900	9.3	9.5	9.5	8.5	9.2	1909	11.6	12.5	8.2	8.2	10.1
1901	10.1	9.9	9.4	8.2	9.4	1910	11.8	10.1	10.1	8.1	10.0
1902	10.2	10.1	10.6	8.6	9.9	1911	11.6	11.6	8.9	8.9	10.3
1903	11.6	11.0	8.4	9.9	10.2	1912	11.6	11.9	9.1	8.3	10.2
1904	12.0	10.5	8.9	8.5	10.0	1913	10.1	8.6	10.2	8.5	9.4
1905	9.9	10.0	10.2	7.9	12.0	1914	13.5	11.1	12.1	9.7	11.6
1906	10.8	10.3	11.9	7.1	10.0	1915	11.8	12.1	12.1	10.8	11.7
1907	11.6	10.0	9.8	7.9	9.8						
1908	11.9	11.5	9.3	7.3	10.0	Average	11.2	10.7	9.9	8.5	9.8

TEMPERATURE.

The maximum, minimum, and mean temperatures for the four months, April to July, of each year during the 16-year period from 1900 to 1915, inclusive, are shown in Table IV. The highest temperature recorded during the entire period was 95° F. and the lowest 4° F. The summers are not extremely hot and the nights are always cool.

TABLE IV.—*Maximum, minimum, and mean temperatures at Cheyenne, Wyo., by months, from April to July of each year, for the 16-year period, 1900 to 1915, inclusive.*

[Data (in ° F.) from the records of the United States Weather Bureau.]

Year.	April.			May.			June.			July.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
1900	69	6	40.2	81	25	54.8	92	40	65.4	90	39	64.9
1901	79	8	40.2	77	31	53.7	90	35	60.0	95	44	71.4
1902	74	9	41.6	82	28	52.8	92	37	61.0	93	40	63.8
1903	71	4	40.0	77	24	48.0	88	30	56.9	89	40	66.8
1904	72	15	41.5	77	26	49.2	80	36	57.2	87	37	63.2
1905	73	12	37.3	77	25	47.2	88	42	61.6	88	42	63.8
1906	74	16	43.2	77	27	51.0	88	33	57.9	88	39	62.9
1907	72	15	39.3	80	8	45.4	83	36	58.1	91	43	66.3
1908	75	7	44.2	81	23	47.8	85	40	57.9	89	36	65.0
1909	70	10	36.0	75	18	46.8	89	41	61.3	93	44	68.0
1910	82	21	46.4	79	25	49.6	91	37	62.7	95	43	69.2
1911	71	14	41.4	79	25	52.2	87	43	64.6	86	42	64.7
1912	62	17	40.2	81	28	50.4	86	33	58.5	86	46	65.0
1913	73	19	43.1	81	28	52.0	88	40	60.8	92	43	65.2
1914	67	12	40.2	76	27	51.1	85	41	61.4	86	43	66.6
1915	70	26	46.0	79	21	46.4	78	29	54.6	89	33	62.3
Average	72	13	41.3	79	24	49.9	87	37	59.9	90	41	65.6

Data showing the dates of the latest frost in spring and the first frost in autumn and the length of the frost-free period for each year from 1900 to 1916 are presented in Table V. These data were obtained from the records of the United States Weather Bureau at Cheyenne, Wyo.

TABLE V.—*Dates of killing frosts, the last in spring and the first in autumn, with the length of the frost-free period, at Cheyenne, Wyo., in each year, 1900 to 1915, inclusive.*

[Data obtained from the records of the United States Weather Bureau.]

Year.	Dates of killing frosts.		Frost-free period.	Year.	Dates of killing frosts.		Frost-free period.
	Last in spring.	First in autumn.			Last in spring.	First in autumn.	
			Days.				*Days.*
1900	May 19	Sept. 26	129	1909	May 25	Sept. 22	119
1901	May 22	Sept. 16	117	1910	May 22	Aug. 25	94
1902	May 21	Sept. 12	113	1911	May 27	Oct. 19	144
1903	June 1	Sept. 14	105	1912	May 14	Sept. 15	123
1904	May 17	...do....	119	1913	May 3	Sept. 20	139
1905	May 16	Oct. 9	145	1914	May 7	Sept. 14	130
1906	May 6	Oct. 4	150	1915	June 13	Oct. 5	114
1907	May 14	Sept. 20	128				
1908	May 10	Sept. 26	138	Average	May 18	Sept. 21	125

The United States Weather Bureau, in reporting killing frosts, uses the staple crops of any given locality as a basis for determining the character of a given frost. Therefore, a temperature of 32° F. is not necessarily a killing frost, depending on the hardiness of the staple crops grown in the area under discussion.

At Cheyenne the average frost-free period is 125 days.

CHEYENNE EXPERIMENT FARM.

LOCATION.

The Cheyenne Experiment Farm is located in Laramie County, in southeastern Wyoming, about 8 miles east of Cheyenne and half a mile southeast of Archer. Archer is on the Union Pacific Railroad, while Cheyenne is on the Union Pacific, the Colorado & Southern, and the Chicago, Burlington & Quincy Railroads. The farm is about

FIG. 2.—Buildings on the Cheyenne Experiment Farm, Archer, Wyo., in 1915. (Photograph lent by the Office of Dry-Land Agriculture Investigations.)

35 miles west of the Nebraska State line and 15 miles north of the Colorado State line. It lies in about 41° 8′ N. latitude and 104° 48′ W. longitude. A view of the farm buildings is shown in figure 2, of the barns and silo in figure 3, and of a farmers' round-up at the station in figure 4.

DESCRIPTION.

The farm consists of 250 acres. It was part of a large cattle ranch and for years had been used for grazing purposes. The soil is a sandy loam, varying in depth from 3 to 6 feet. Below these depths the soil is gravelly or sandy. The surface soil contains a low percentage of humus.

The farm slopes gently a little south of east and excellent surface drainage is afforded.

A map of the farm is shown in figure 5. The experimental work has been conducted on the west field. This field, of about 100 acres, is laid out in series lettered from A to L, inclusive. Each contains 67 tenth-acre plats except series J, K, and L, each of which contains only 46 tenth-acre plats. Eighteen acres of this field are devoted to rotation experiments under the direction of the Office of Dry-Land Agriculture Investigations. The soil on the entire experimental area is as uniform as can be expected in this district and is fairly representative of the soil of southeastern Wyoming.

SCOPE OF THE EXPERIMENTS.

Varietal experiments in plats have been conducted with winter and spring wheat, emmer, and oats, and with spring barley, flax, and proso. Rate-of-seeding and date-of-seeding tests have been made with winter wheat and with spring wheat, oats, barley, and flax.

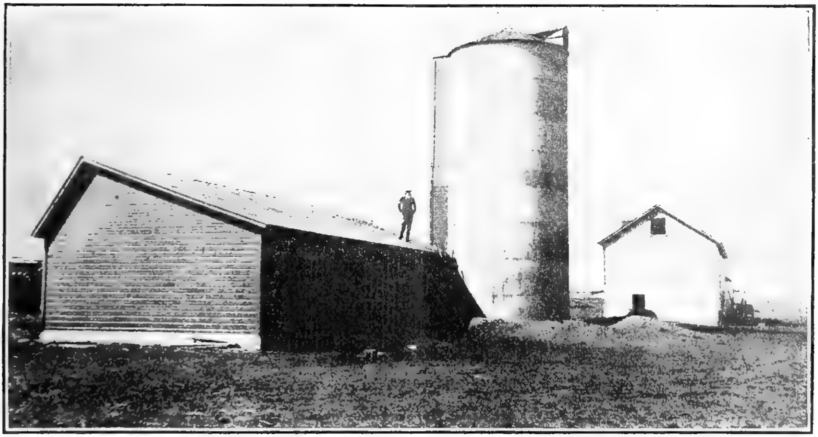

FIG. 3.—Silo and cow barn on the Cheyenne Experiment Farm, Archer, Wyo. (Photograph lent by the Office of Dry-Land Agriculture Investigations.)

In 1913, 7 varieties of winter wheat, 1 of winter emmer, 32 varieties and 11 pure lines of spring wheat, 14 varieties of oats, 16 of barley, 12 of flax, 8 of proso, and 8 of grain sorghum were grown at Archer. Rate-of-seeding and date-of-seeding tests with 2 winter wheats, 1 spring wheat, 1 spring oats, and 1 spring barley and a date-of-seeding test with flax were also conducted. In 1914 the number of winter wheats was materially increased. A few flax varieties and a rate-of-seeding test with flax also were added. In 1915 the number of varieties and experiments was about the same as in 1914.

EXPERIMENTAL METHODS.

Two general methods of experimentation have been used at Archer. Cereal varieties have been tested in field plats and in nursery rows. It is possible to test economically a much larger number of varieties in the nursery than in the plats. Only the data obtained from the plat tests are reported in this paper. All rate-of-seeding and date-of-seeding experiments have been conducted on field plats.

SIZE AND ARRANGEMENT OF PLATS.

In 1913 and 1914 tenth-acre plats were used in varietal, rate-of-seeding, and date-of-seeding experiments. The plats were 2 by 8 rods, or 33 by 132 feet, arranged in series of 67 plats. The plats in each series were separated by 5-foot alleys and the series of plats were separated by 20-foot roadways. Thus each plat was bordered on each side by a 5-foot alley and on each end by a 20-foot road. In 1915 the plats used were a thirtieth and a twentieth of an acre, being 11 by 132 feet and 16.5 by 132 feet, respectively. The thir-

FIG. 4.—Farmers' round-up on the Cheyenne Experiment Farm, Archer, Wyo. Each year the farmers in the community visit the station and inspect the experimental work. (Photograph lent by the Office of Dry-Land Agriculture Investigations.)

tieth-acre plats were separated by 18-inch alleys and the twentieth-acre plats by 30-inch alleys. Thus the thirtieth-acre plats were bordered on the sides by 18-inch alleys and on the ends by 20-foot roads. The twentieth-acre plats had 30-inch alleys on each side and 20-foot roads on each end. The long dimension of the series extended east and west, while that of the plats extended north and south. The series are designated by the letters A to M. The plats are numbered from 1 to 67, inclusive.

REPLICATION OF PLATS.

In 1913 the winter wheats were grown in duplicate tenth-acre plats. The spring wheats and other spring cereals were grown in single tenth-acre plats. In 1914 all winter and spring cereals were grown in single tenth-acre plats except a few spring-wheat varieties, which were grown in triplicate tenth-acre plats. In 1915 the winter-wheat varieties were grown in triplicate thirtieth-acre plats and most of the spring cereals in duplicate twentieth-acre plats.

PREPARATION OF THE LAND.

In the preparation of the seed bed the aim at Archer has been to do the work in as practical a manner as possible. However, at times the land has probably been given better preparation than would be profitable on the average farm.

All crops were grown on breaking in 1913 and on fallow land in 1914. In 1915 the winter wheats were grown on fallow and all spring crops on land which had produced corn the previous year.

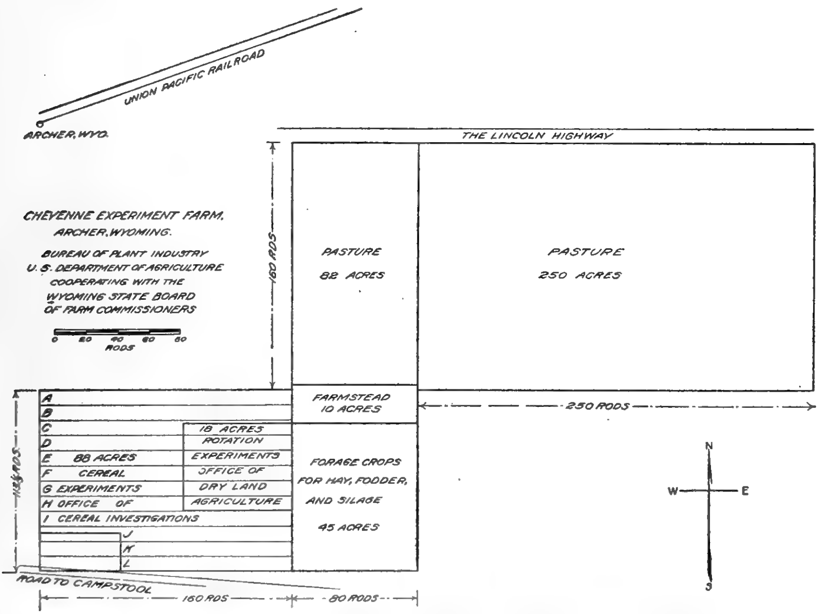

FIG. 5.—Map of the Cheyenne Experiment Farm, Archer, Wyo., showing the location of the principal experiments and the manner in which the farm is divided into series and plats.

RATES AND DATES OF SEEDING.

In the varietal experiments at Archer, winter and spring wheats have been seeded at the rate of 3 pecks per acre. The small-kerneled early oats have been sown at the rate of 4 pecks, and the larger kerneled midseason varieties at the rate of 5 pecks per acre. Barley has been sown at the rate of 4 pecks and flax at 15 pounds per acre.

Winter wheat, except in the fall of 1912, has been seeded between September 1 and 15. Spring wheat, oats, and barley have been sown between April 15 and May 1. Flax and proso have been seeded between May 15 and 25.

INTERPRETATION OF EXPERIMENTAL RESULTS.

The interpretation of the results obtained from plat experiments is difficult. This is due to the large number of factors which must be considered in determining the relative value of different varieties or different cultural methods. Generally speaking, the variety that gives the highest average yield of good quality in a period of several years is the one that should be grown. It is really quite difficult to obtain a variety that is consistently a high yielder and also is high in quality. Variations in soil and seasonal and annual variations in climate have a great influence on crop production in dry-land areas. All these factors must be thoroughly studied, in order that reliable conclusions may be drawn. The experiments at the Cheyenne Experiment Farm have been under way for only three years. This is too brief a period to give the needed long-time average of yields or to permit sufficient study of soil and climatic variations.

EXPERIMENTS WITH WHEAT.

At Archer, experiments with winter and spring varieties of wheat have been conducted in field plats and nursery rows. Most of the work, however, has been done on field plats. Wheat is the leading crop in southeastern Wyoming. Spring and winter varieties are grown on about equal acreages. More work has been done at Archer with wheat than with any other cereal.

WINTER WHEAT.

Experiments with winter wheat have included varietal, rate-of-seeding, and date-of-seeding experiments. The work at Archer is relatively new. Therefore little has been done in the improvement of crop varieties. The work has been confined for the most part to the testing of varieties known to be the most promising for the dry-land districts.

VARIETAL EXPERIMENTS.

The varietal experiments with winter wheat on the Cheyenne Experiment Farm have included for the most part the hard, red winter varieties of the Crimean group. Seven varieties have been grown for three years, 1913, 1914, and 1915, while eight additional varieties have been grown for two years, 1914 and 1915. The annual and average yields of winter-wheat varieties are presented in Table VI.

In 1913, seven winter-wheat varieties and strains were grown in duplicate tenth-acre plats on sod that was broken in August, 1912, double disked twice, and harrowed. The plowing was poorly done and the seed bed was rather rough. The seed was sown on October 5, 1912. The plants emerged on October 25, but made little growth before winter. The stands obtained were rather thin, but tillered enough the next spring to make fair yields. The rainfall during the growing season was below normal.

In 1914, 15 varieties and strains of winter wheat were grown in tenth-acre plats on fallow land. The land was plowed in the fall of 1912 and left rough until the spring of 1913, when it was double-disked and kept free from weeds during the summer. The varieties were sown September 9, 1913. The fall of 1913 was wet, and good stands of all varieties were obtained. The winter wheats were 3 to 6 inches high when winter began. The winter was cold and open, and practically all varieties winterkilled considerably. A few plats apparently were favorably located, and on these the winter survival was much higher than on the others. The winterkilling was not uniformly distributed on the plats, but occurred in patches or streaks. The survival of a variety did not necessarily indicate winter hardiness, since the same variety sown on different plats had a markedly different winter survival. However, certain soft winter wheats less hardy than those of the Crimean group were entirely winterkilled. It is believed that the yields reported in Table VI are representative of what could reasonably have been expected from winter wheat on fallow land in 1914, as winterkilling was quite general on farms in the vicinity. The precipitation for the growing season was below normal, as shown in Table I.

TABLE VI.—*Annual and average yields of varieties of winter wheat grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C. I. No.	Yield per acre (bushels).				
		[a] 1913	1914	[b] 1915	Average. 3 years, 1913 to 1915.	Average. 2 years, 1914 and 1915.
Crimean:						
Kharkof	1442	9.8	4.7	37.1	17.2	20.9
Crimean	1559	9.7	3.2	38.6	17.2	20.9
Do	1432	9.5	4.7	36.1	16.8	20.4
Turkey	1571	10.0	[c] 7.9	32.0	16.6	20.0
Malakoff	2908	10.3	0	37.6	16.0	18.8
Crimean	1437	9.2	2.5	35.1	15.6	18.8
Turkey	2998	....	13.7	32.5	....	23.1
Alberta Red	2979	....	7.7	37.8	....	22.8
Beloglina	1543	....	5.0	36.8	....	20.9
Kharkof	1583	....	6.0	35.6	....	20.8
Armavir	1355-2-2	....	4.0	32.6	....	18.3
Miscellaneous:						
Ghirka Winter	1438	9.3	7.8	37.6	18.2	22.7
Diehl Mediterranean	1359	....	4.5	38.0	....	21.3
Buffum No. 17	3330	....	12.8	27.1	....	20.0
Red Russian	1532	....	5.6	32.8	....	19.2

[a] Average of 2 tenth-acre plats.
[b] Average of 3 thirtieth-acre plats.
[c] Average of 3 tenth-acre plats (checks).

For the 1915 crop the winter wheat varieties were sown on September 8, 1914, in triplicate on thirtieth-acre plats. They were sown on fall-plowed fallow land that had been kept free from weeds during the summer of 1914. The stands obtained and growth made before winter were good. The winter survival was high. The seasonal rainfall was considerably above normal, while the temperature was below normal during the growing season. The varieties yielded very well in 1915, as is shown in Table VI.

Table VII shows the agronomic data for seven varieties of winter wheat grown at Archer in the three years 1913, 1914, and 1915. These data include average dates of heading and maturity, height, weight per bushel, yield of grain and of straw, and ratio of grain to straw. The weight per bushel is for the two years 1914 and 1915. The weight per bushel was low in 1914, the grain being shrunken. The highest average yield, 18.2 bushels per acre, was produced by the

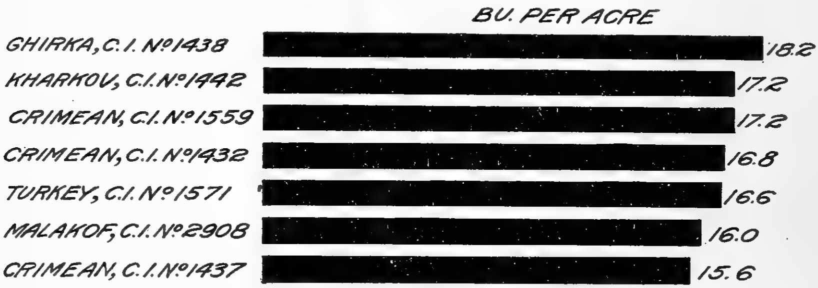

FIG. 6.—Diagram showing the average yields of seven varieties of winter wheat on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.

Ghirka Winter wheat (C. I. No. 1438). The lowest average yield, 15.6 bushels, was obtained from the Crimean (C. I. No. 1437). The ratio of grain to straw was lowest for Ghirka Winter and highest for Crimean (C. I. No. 1432). The average ratio for the seven varieties is about 1:2. In figure 6 the yields of the seven varieties of winter wheat grown at Archer from 1913 to 1915, inclusive, are shown graphically.

TABLE VII.—*Average date of heading and maturity, height, weight per bushel, yields, and ratio of grain to straw of seven varieties of winter wheat grown on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.*

Group and variety.	C. I. No.	Dates of—		Height.	Weight per bushel.[1]	Yield per acre.		Ratio, grain to straw.
		Heading.	Maturity.			Grain.	Straw.	
Ghirka:				*Inches.*	*Pounds.*	*Bush.*	*Pounds.*	
Ghirka Winter	1438	June 29	July 28	27	61	18.2	2,018	1:1.85
Crimean:								
Kharkof	1442	...do....	July 26	28	58	17.2	2,170	1:2.10
Crimean	1559	..do....	...do....	28	60	17.2	1,847	1:1.79
Do	1432	July 2	July 30	26	60.5	16.8	2,463	1:2.44
Turkey	1571	June 29	July 26	28	60	16.6	2,040	1:2.05
Malakoff	2908	[1] July 2	[1] July 31	[1] 30	62	16.0	1,769	1:1.84
Crimean	1437	June 29	July 27	27	58.5	15.6	1,804	1:1.93

[1] Average for two years.

The leading varieties of winter wheat, with the exception of the Ghirka Winter, belong to the Crimean group. The Ghirka Winter is a beardless variety with white, glabrous chaff and hard, red kernels. The Crimean group is characterized by bearded heads with white, glabrous chaff and hard, red kernels. Turkey is the leading variety on the farms in this section of Wyoming. A plat of Turkey winter wheat on the Cheyenne Experiment Farm is shown in figure 7.

RATE-OF-SEEDING EXPERIMENT.

A rate-of-seeding experiment has been conducted at the Cheyenne Experiment Farm since 1913 with two varieties of winter wheat. The rates of seeding have ranged from 2 to 7 pecks per acre. The

FIG. 7.—A plat of winter wheat on disked corn land on the Cheyenne Experiment Farm, 1915. (Photograph lent by the Office of Dry-Land Agriculture Investigations.)

annual and average yields in the rate-of-seeding test of the Turkey and Ghirka Winter wheats are shown in Table VIII.

TABLE VIII.—*Annual and average yields of the Turkey and Ghirka Winter wheats in a rate-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Variety and rate of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
Turkey:	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
2 pecks	....	....	0	0	32.5	4,070	....	....
3 pecks	9.1	715	0	0	35.5	4,990	14.9	1,902
4 pecks	9.0	585	0	0	32.0	4,540	13.7	1,708
5 pecks	10.1	830	0	0	34.8	5,030	15.0	1,953
6 pecks	10.4	750	0	0	35.1	5,090	15.2	1,947
7 pecks	9.9	680	0	0	....	....	....	....
Ghirka Winter:								
2 pecks	....	....	0	0	35.8	4,700	....	....
3 pecks	9.3	600	0	0	35.5	5,080	14.9	1,893
4 pecks	7.4	450	0	0	32.8	5,130	13.8	1,860
5 pecks	8.6	595	0	0	31.3	5,040	13.3	1,878
6 pecks	9.3	650	0	0	30.5	4,920	13.3	1,890
7 pecks	7.5	750	0	0	....	....	....	....

In 1913 the sowings were in tenth-acre plats on land that was plowed in August, double disked twice, and harrowed before seeding. The sowings were made on October 5, 1912. Little or no winterkilling occurred. The seasonal rainfall was below normal and the yields were relatively low. With the Turkey the highest yields were obtained from the 5-peck and 6-peck rates, while with the Ghirka Winter the 3-peck and 6-peck rates gave the highest yields.

In 1914 the two varieties were again grown in tenth-acre plats on fallow land. The seed was sown on September 10, 1913. There was sufficient moisture present in the soil to start germination immediately and a good fall growth resulted. The winter was cold and open, and as a result all rate sowings were so badly winterkilled that the plats were reseeded to spring crops.

In 1915 the rate-of-seeding test included rates of 2 to 6 pecks per acre. Sowings were made on September 9, 1914, in triplicate thirtieth-acre plats on fallow land. The stands obtained were good and an excellent fall growth resulted. All plats had a high winter survival and the yields were high. The 3-peck and 6-peck rates gave the highest yields with the Turkey wheat, while with the Ghirka Winter there was a gradual decrease in yield as the rate of seeding increased.

The average yields for the three years, 1913 to 1915, inclusive, are shown in Table VIII. With the Turkey, the highest average yields were obtained from the 3-peck, 5-peck, and 6-peck rates of seeding. The differences in yields from these rates were very small. With the Ghirka Winter the highest average yield was obtained from the 3-peck rate of seeding. Light seeding probably is to be preferred. It is the practice on the farms to sow about 3 pecks per acre in this section.

DATE-OF-SEEDING EXPERIMENTS.

Date-of-seeding experiments with the Turkey and Ghirka Winter wheats have been conducted since 1913. The annual and average yields obtained from the date-of-seeding tests are shown in Table IX.

In 1913 the sowings were in tenth-acre plats on breaking. The highest yields were from the earlier sowings. In 1914 the sowings were in tenth-acre plats on fallow land. Better stands and better fall growth were obtained from the earlier sowings. Winterkilling was severe on all plats. The plats of both varieties sown September 1 survived the winter best and were harvested. The plats sown on other dates were reseeded to spring crops.

In 1915 the sowings were in triplicate thirtieth-acre plats on fallow land. Good stands and excellent fall growth were obtained from the three earlier seedings. From the two later seedings fair stands were obtained, but there was very little fall growth. The plats of the Turkey wheat sown on September 1 and 15 gave the highest yields. With Ghirka Winter, the plats sown on September 1 and 15 and October 1 all yielded practically the same. The September 15 sowing gave slightly the highest yield. The results to date seem to indicate that early seeding (September 1 to 20) is to be preferred, provided conditions are favorable to germination and fall growth. The farmers in this section practice early seeding when possible.

TABLE IX.—*Annual and average yields of the Turkey and Ghirka Winter wheats in a date-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Variety and date of seeding.	Yield per acre.									
	1913		1914		1915		Average.			
							1913 to 1915		1914 and 1915	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
Turkey:										
Aug. 15	...	...	0	0	29.6	3,400	...	...	14.8	1,700
Sept. 1	...	...	6.8	1,145	38.1	4,460	...	...	22.5	2,802
Sept. 15	...	...	0	0	38.8	4,430	...	...	19.2	2,215
Oct. 1	8.8	635	0	0	34.5	3,140	14.4	1,258	17.2	1,570
Oct. 15	8.5	673	0	0	25.6	2,220	11.4	964	12.8	1,110
Nov. 1	6.7	455	0	0	...	...	...	...	...	...
Ghirka Winter:										
Aug. 15	...	...	0	0	27.0	2,970	...	...	13.5	1,485
Sept. 1	...	...	7.8	910	29.3	3,630	...	...	18.6	2,270
Sept. 15	...	...	0	0	31.3	4,140	...	...	15.7	2,070
Oct. 1	8.4	505	0	0	30.1	3,070	12.8	1,192	15.0	1,535
Oct. 15	8.4	545	0	0	17.1	1,690	8.5	745	8.5	845
Nov. 1	6.1	390	0	0	...	...	...	...	...	...

SPRING WHEAT.

Spring wheats are grown as extensively in eastern Wyoming as winter wheats. A greater number of varieties of spring wheat than of winter wheat have been tested at the Cheyenne Experiment Farm. Thirty-three varieties and strains have been included in the experiments during the three years, 1913, 1914, and 1915. The annual and average yields of these varieties are shown in Table X.

These varieties may be divided into two classes, common and durum. These classes may be separated further into groups. Eighteen of the varieties are common wheats and 15 are durum wheats. These two classes of wheat and the most important groups of each which are represented in the Great Plains area may be separated by the following descriptive key: [1]

[1] Ball, C. R., and Clark, J. A. Varieties of hard spring wheat. U. S. Dept. Agr., Farmers' Bul. 680, p. 6, 9, 18. 1915.

Descriptive key to varieties of spring wheat.

Heads rather slender, beardless or beards less than 3 inches long; spikelets far apart, scarcely overlapping, wide when seen in face view .... COMMON WHEAT.
- Heads beardless:
  - Chaff white, glabrous .... 1. Fife.
  - Chaff white, pubescent .... 2. Bluestem.
- Heads bearded:
  - Chaff white, glabrous .... 3. Preston.

Heads rather stout, all bearded, beards 4 to 8 inches long; spikelets close together, much overlapping, narrow when seen in face view .... DURUM WHEAT.
- Chaff yellowish:
  - Chaff glabrous—
    - Beards yellow .... 1. Kubanka.
    - Beards black .... 2. Pelissier.
  - Chaff pubescent—
    - Beards black .... 3. Velvet Don.
- Chaff black:
  - Chaff slightly pubescent—
    - Beards black .... 4. Kahla.

VARIETAL EXPERIMENTS.

The varietal experiments with spring wheat are reported here in two separate series. The first contains the varieties grown in the regular varietal test. The second contains some lots obtained from the Minnesota experiment station in the spring of 1913, too late for inclusion in the regular series. All except one were discarded at the end of 1915. They were not grown in any of the three years on plats comparable in size with those of the regular series. The annual and average yields of the 33 varieties and strains of spring wheat grown in the regular varietal test in 1913, 1914, and 1915 are shown in Table X.

In 1913 the varieties of spring wheat included in Table X were sown on April 25 and 26 in tenth-acre plats on land that was broken in October, 1912. It lay in the rough until the spring of 1913, when it was double disked and harrowed before seeding. Good stands were obtained of practically all varieties. The spring was rather cold and late. Precipitation during the growing season was below normal, as is shown in Table II. A hailstorm on June 19 damaged the varieties slightly. The yields in 1913 ranged from 1.3 bushels from Crossbred (C. I. No. 3695) to 9.4 bushels from Erivan (C. I. No. 2397). The average yield of the 14 durum varieties was 7.7 bushels, while that of the 18 common spring varieties was 6.3 bushels per acre. The best variety of durum wheat yielded 8.8 bushels, 1.4 bushels less than the best common wheat.

In 1914 the spring-wheat varieties were sown on April 21 and 22 in tenth-acre plats on spring-plowed fallow land. Good stands were obtained on all plats. The spring was late, cool, and wet. The precipitation for the growing season was below normal. A hailstorm on June 14 damaged the spring wheat to some extent. During both 1913 and 1914 the crop prospects were excellent until about June 1, when the crops began to suffer from drought. The yields in 1914, as shown in Table X, ranged from 3.1 bushels per acre for Crossbred (C. I. No. 3695) to 13 bushels per acre for Kubanka (C. I. No. 1516). The average yield of the 14 durum varieties was 12 bushels, while the average yield of the 18 spring common varieties was 8.9 bushels per acre. The best variety of durum yielded 13 bushels, or 2.6 bushels more than the best common wheat.

TABLE X.—*Annual and average yields of 33 varieties and strains of spring wheat grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C. I. No.	Yield per acre (bushels).			
		1913	1914	[a] 1915	3-year average.
COMMON WHEATS.					
Preston:					
Erivan	2397	9.4	9.5	22.0	13.6
Red Russian	4141	8.3	10.2	19.0	12.5
Spring Turkey	4154	8.7	8.5	19.5	12.2
Common Spring	1541	7.2	9.3	19.3	11.9
Preston	3698	6.7	9.8	15.3	10.6
Do	3081	4.7	8.1	14.8	9.2
Unclassified:					
Galgalos	2398	[b] 7.9	[c] 10.3	21.2	13.1
Defiance	3703	7.7	9.3	9.5	8.8
Fife:					
Cole Hybrid	4062	8.5	10.4	19.7	12.9
Marquis	3641	9.0	[c] 8.4	20.9	12.8
Ghirka Spring	1517	[b] 9.2	[c] 10.0	13.2	10.8
Rysting	3022	8.3	[c] 8.1	11.7	9.4
Glyndon (Minn. No. 163)	2873	[b] 5.8	9.6	12.5	9.3
Power	3697	4.7	7.3	12.3	8.1
Bluestem:					
Haynes (Minn. No. 169)	2874	[b] 4.4	[c] 9.0	11.7	8.4
Marvel	3082	3.4	6.5	11.2	7.0
Haynes	3021	2.6	5.3	10.7	6.2
Crossbred	3695	1.3	3.1	9.0	4.5
DURUM WHEATS.					
Kubanka:					
Beloturka	1520	7.7	11.9	28.9	16.2
Kubanka	1516	7.1	13.0	27.6	15.9
Pererodka	1350	8.3	12.8	26.0	15.7
Kubanka	1440	7.5	12.5	25.6	15.2
Yellow Gharnovka	1444	7.8	11.5	25.9	15.1
Gharnovka	1447	7.5	12.3	24.1	14.6
Arnautka	1493	[d] 7.2	[e] 12.3	23.8	14.4
Kubanka	1354	7.7	12.8	22.1	14.2
Marouani	1593	7.9	[c] 11.5	21.5	13.6
Arnautka	4064	[b] 6.4	10.7	23.6	13.6
Pelissier:					
Pelissier	1584	[b] 8.7	[c] 11.6	22.6	14.3
Saragolla	2228	6.7	10.3	18.8	11.9
Velvet Don:					
Velvet Don	1445	8.6	10.8	24.4	14.6
Kahla:					
Purple	3024	[b] 7.5	[c] 10.5	22.8	13.6
Blé dur	1471	7.3	11.8	[f] 13.1	10.7

[a] Average of 2 twentieth-acre plats.
[b] Average of 2 tenth-acre plats.
[c] Average of 3 tenth-acre plats.
[d] Average of 15 check plats.
[e] Average of 12 check plats.
[f] Severely rogued.

In 1915 the spring-wheat varieties were sown April 27 and 28 and May 4 in duplicate twentieth-acre plats. These were on corn stubble that had been double disked and harrowed once previous to seeding. Good stands were obtained on all plats. The spring was late, cool, and wet. The precipitation during the growing season was considerably above normal, due to the high precipitation of April. The entire growing season was cool and favorable to crop growth. Hailstorms on July 5 and August 17 probably did some damage to the spring wheats. However, the most serious damage was due to rust, which affected all the spring common varieties. The lowest yield in 1915 was 9 bushels, from Crossbred (C. I. No. 3695), and the highest 28.9 bushels per acre, from Beloturka (C. I. No. 1520). The average yield of the 15 durum varieties was 23.4 bushels, while the average yield of the 18 spring common varieties was 15.2 bushels per acre.

Table XI shows the rank of the groups of spring wheats when arranged according to yields to be as follows: (1) Durum, (2) Preston, (3) unclassified (4) Fife, and (5) Bluestem. Table XI also shows certain agronomic data, including the average dates of heading and maturity, height, weight per bushel, yield, and the ratio of grain to straw, for the leading varieties of spring wheat grown on the Cheyenne Experiment Farm from 1913 to 1915, inclusive.

TABLE XI.—*Average dates of heading and maturity, height, weight per bushel, yields, and ratio of grain to straw, for 16 varieties of spring wheat grown on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.*

Group and variety.	C. I. No.	Date of—		Height.	Weight per bushel.[1]	Yield per acre.		Ratio, grain to straw.
		Heading.	Maturity.			Grain.	Straw.	
				Inches.	*Lbs.*	*Bush.*	*Lbs.*	
Durum:								
Beloturka	1520	July 13	Aug. 18	28	62.0	16.2	1,215	1 : 1.25
Kubanka	1516	...do.....	Aug. 17	27	61.5	15.9	1,222	1 : 1.28
Pererodka	1350	...do.....	Aug. 18	29	62.0	15.6	1,395	1 : 1.49
Kubanka	1440	...do.....	...do.....	27	61.7	15.2	1,197	1 : 1.31
Preston:								
Erivan	2397	July 15	Aug. 15	21	58.0	13.6	1,188	1 : 1.46
Red Russian	4141	July 16	Aug. 16	24	58.0	12.5	1,273	1 : 1.70
Spring Turkey	4154	July 17	Aug. 17	25	60.0	12.2	1,240	1 : 1.69
Unclassified:								
Galgalos	2398	July 15	Aug. 16	22	59.2	13.1	983	1 : 1.25
Defiance	3703	July 18	Aug. 18	25	53.2	8.8	1,063	1 : 2.01
Fife:								
Cole Hybrid	4062	July 17	...do.....	27	58.5	12.9	1,268	1 : 1.64
Marquis	3641	July 15	Aug. 16	24	58.5	12.8	1,056	1 : 1.37
Ghirka Spring	1517	July 14	...do.....	25	56.5	10.8	1,015	1 : 1.57
Rysting	3022	July 20	Aug. 18	25	54.2	9.4	1,297	1 : 2.30
Glyndon (Minn. No. 163)	2873	July 18	Aug. 19	23	55.7	9.3	1,221	1 : 2.19
Bluestem:								
Haynes (Minn. No. 169)	2874	...do.....	...do.....	24	51.0	8.4	1,095	1 : 2.17
Marvel	3082	July 21	Aug. 21	25	53.5	7.0	1,147	1 : 2.73

[1] Average for two years.

The durum wheats have headed earlier than the spring common wheats, but have been a little later in maturing than the leading varieties of common wheat. The durum varieties also have grown taller, weighed more per measured bushel, yielded higher, and given a higher ratio of grain to straw than the spring common varieties.

The yields of the leading varieties of each group are shown graphically in figure 8.

MISCELLANEOUS MINNESOTA VARIETIES.

Eleven lots of Fife, Bluestem, and Preston wheats were obtained from the Minnesota Agricultural Experiment Station late in the spring of 1913. They were sown in fiftieth-acre plats on breaking. The stands were good, except that of McKendry (C. I. No. 4147). These wheats were shattered about 15 per cent by hail on August 16. All were late in maturing and the yields were low.

In 1914 these wheats were sown on fallow land in plats of varying size. Good stands were obtained. Yields were better in 1914 than in 1913.

In 1915 the wheats were sown in single twentieth-acre plats on double-disked corn ground. The stands obtained were good. While

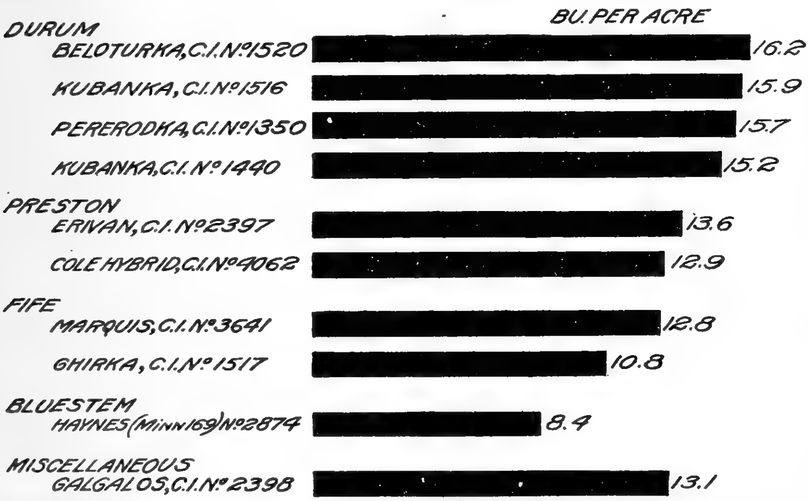

FIG. 8.—Diagram showing the average yields of the leading varieties in each group of spring wheat on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.

the varieties were damaged by rust, the yields obtained were fairly good, as is shown in Table XII, but the quality was poor. The average yields of these wheats in the three years, 1913 to 1915, inclusive, are much lower than those obtained from most of the varieties in the regular varietal test (Table X).

LEADING VARIETIES.

The leading durum wheats have yielded from 2 to 3 bushels per acre more than the leading common wheats. Yields from the leading varieties of the Preston, Fife, and miscellaneous groups have been practically the same. The Bluestem varieties have been consistently the lowest in yield.

TABLE XII.—*Annual and average yields of 11 spring common wheats from Minnesota grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C. I. No.	Minn. No.	Yield per acre (bushels).			
			1913	1914	1915	3-year average.
Preston:						
Velvet Chaff	4153	1011	1.3	6.9	15.0	7.7
Fife:						
Glyndon	4143	163	2.0	3.7	9.3	5.0
Do	4146	285	1.5	4.1	10.3	5.3
McKendry	4147	288	4.0	[a] 7.3	9.7	7.0
Do	4152	903	2.5	4.2	10.7	5.8
Power	4150	886	.4	[a] 8.3	9.3	6.0
Do	4151	899	1.3	4.6	11.0	5.6
Rysting	4148	476	2.2	4.1	10.3	5.5
Wellman	4144	165	3.0	7.0	12.7	7.6
Bluestem:						
Bolton	4142	146	.6	4.6	10.0	5.1
Haynes	4145	169	.6	[a] 9.5	11.3	7.1

[a] Damaged by hail.

The leading varieties of durum wheat at Archer belong to the Kubanka group. This group of durums has broad heads with long, pale awns, yellowish, glabrous glumes, and large, hard, amber kernels. The Beloturka, Kubanka, and Pererodka varieties have given the highest average yields.

The spring common wheats grown at Archer are divided into four groups. The Preston group has bearded heads, white glabrous glumes, and hard red kernels. The Fife group has beardless heads, white glabrous glumes, and hard red kernels. The bluestem group has beardless heads, white pubescent glumes, and hard red kernels. The unclassified group includes some varieties which do not belong in any of the three groups just described. The Galgalos variety has a beardless head, brown pubescent glumes, and large soft white kernels. The Defiance has a beardless head, white glabrous glumes, and soft white kernels. The leading varieties in each of these groups are shown in Table XI.

RATE-OF-SEEDING EXPERIMENT.

A rate-of-seeding experiment with Arnautka durum wheat has been conducted at the Cheyenne Experiment Farm for three years, 1913 to 1915, inclusive. The annual and average yields obtained are shown in Table XIII.

In 1913 the rate-of-seeding test was sown in tenth-acre plats on breaking. Good stands were obtained from all rates. The highest yield was obtained from the 2-peck rate.

In 1914 the rate-of-seeding test was sown in tenth-acre plats on fallow land that had been spring plowed. Good stands were obtained. The highest yield was produced on the plat sown at the rate of 4 pecks per acre.

In 1915 the rate-of-seeding test was sown in duplicate twentieth-acre plats on double-disked corn ground. The highest yield was obtained from the 2-peck rate. For the three years, the 2-peck rate of seeding gave the highest average yield. However, there is little difference in the average yields at the 2-peck, 3-peck, and 4-peck rates.

TABLE XIII.—*Annual and average yields of Arnautka durum wheat in a rate-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Rate of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
2 pecks	10.0	625	9.5	1,220	26.4	2,180	15.3	1,342
3 pecks	9.2	800	10.3	1,060	24.3	2,140	14.6	1,333
4 pecks	8.4	725	10.8	985	26.1	2,120	15.1	1,277
5 pecks	8.3	660	8.6	1,070	24.9	2,100	13.9	1,277
6 pecks	7.8	610	9.2	1,050	23.8	1,950	13.6	1,203
7 pecks	6.0	505	10.5	970	25.3	2,040	13.9	1,172

DATE-OF-SEEDING EXPERIMENT.

A date-of-seeding experiment with Spring Turkey common wheat has been conducted at the Cheyenne Experiment Farm during the three years, 1913, 1914, and 1915. The annual and average yields obtained in this test are shown in Table XIV.

TABLE XIV.—*Annual and average yields of Spring Turkey common wheat in a date-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Date of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
Apr. 15	[a] 16.7	850	8.3	890	15.8	1,890	13.7	1,210
May 1	9.3	625	8.6	935	16.5	1,680	11.5	1,080
May 15	9.1	750	6.4	765	12.8	1,830	9.4	1,115

[a] Computed yield.

In 1913 the date-of-seeding test was sown in tenth-acre plats on fall-plowed breaking. The stands obtained were good. The earlier date of seeding gave the highest yield. The drill failed to sow a portion of the plat sown on April 15. The portion actually seeded, one-fifteenth of an acre, was harvested, and the yield computed on a tenth-acre basis.

In 1914 the date-of-seeding test was sown in tenth-acre plats on spring-plowed fallow land. Stands were good. The highest yield was obtained from the May 1 seeding.

In 1915 the test was sown in duplicate twentieth-acre plats on double-disked corn ground. The highest yield was obtained again from the May 1 seeding. The results to date indicate that fairly early spring sowing is to be preferred.

COMPARISON OF WINTER AND SPRING WHEATS.

In comparing the results from winter wheats, durum wheats, and spring common wheats it is observed that (1) better yields were obtained in 1913 from winter wheats, yet the difference in yield of the leading varieties of winter and spring wheat was not very great. (2) Better yields were obtained in 1914 from the spring wheats, the winter wheats being severely winterkilled. (3) In 1915 winter-wheat yields were much higher than those of spring wheat. (4) The average yields of the winter wheats in the years 1913, 1914, and 1915 are higher than those of any of the spring-wheat groups. (5) Durum wheats stand next to winter wheat when ranked according to yield. (6) Winter wheats undoubtedly will give higher yields than spring wheats if winterkilling is not too severe.

The annual and average yields of some of the leading varieties of winter and spring wheats for the three years, 1913 to 1915, are shown in Table XV.

TABLE XV.—*Annual and average yields of the leading varieties of winter, durum, and spring common wheats grown on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.*

Group and variety.	C. I. No.	Yield per acre (bushels).			
		1913	1914	1915	3-year average.
WINTER WHEAT.					
Ghirka:					
Ghirka Winter	1438	9.3	7.8	37.6	18.2
Crimean:					
Kharkof	1442	9.8	4.7	37.1	17.2
SPRING WHEAT.					
Durum:					
Beloturka	1520	7.7	11.9	28.9	16.2
Common:					
Erivan	2397	9.4	9.5	22.0	13.6
Galgalos	2398	[a] 7.9	[b] 10.3	21.2	13.1
Marquis	3641	9.0	8.4	20.9	12.8

[a] Average of 2 tenth-acre plats. [b] Average of 3 tenth-acre plats.

The average yields of winter and spring wheat are not strictly comparable, since the winter wheats were grown on fallow in 1915, while the spring wheats were grown on disked corn ground.

It appears that it may be more profitable to grow spring wheat, especially the durums, after corn if the corn crop is profitable for forage. It may be possible also to grow winter wheat after corn, but data are not available at present. More data must be obtained before it will be possible to say whether winter or spring wheat is the more profitable. The average yields of the leading varieties of each group of wheats are shown graphically in figure 9.

EXPERIMENTS WITH EMMER AND SPELT.

One variety each of winter and of spring emmer has been grown at Archer during the 3-year period, 1913 to 1915, inclusive.

WINTER EMMER.

Black Winter emmer has been tested each year. In 1912 a tenth-acre plat was sown and about 50 per cent survived the winter. This plat yielded at the rate of 14.2 bushels per acre. In 1913 several plats were seeded at different rates. The stands and fall growth were good on all plats, but the crop entirely winterkilled. In 1914 three twentieth-acre plats were sown to winter emmer at different rates. A fair stand was obtained and the winter survival was high. The average yield of the three plats was about 20 bushels per acre.

Winter emmer has not survived the winters as well as winter wheat and the yields have been much lower. Winter emmer evidently is not adapted to conditions on the high western plains. The average

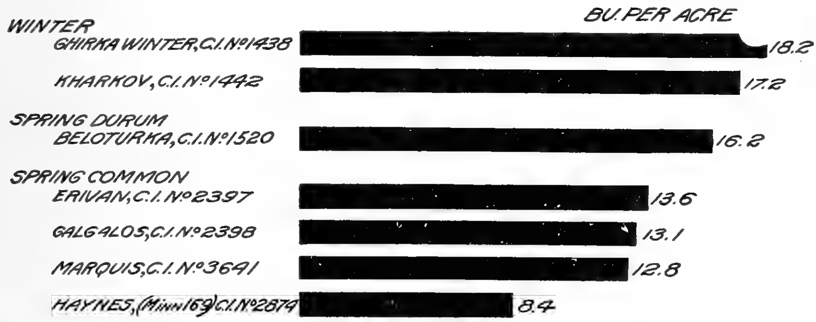

FIG. 9.—Diagram showing the average yields of the leading varieties of winter and spring wheat on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.

yields of emmer at the Cheyenne Experiment Farm have been lower than those of either spring oats or barley.

Winter emmer is drought resistant, but it is not nearly so hardy as the Crimean group of winter wheats. The data available indicate that Black Winter emmer is a doubtful crop in eastern Wyoming and growing it should not be encouraged at present.

SPRING EMMER.

White Spring emmer has been grown at Archer in each of the three years, 1913 to 1915, inclusive. In 1913 a tenth-acre plat was sown. The stand obtained was too thick and the growth was short. The plat yielded at the rate of 7.2 bushels per acre. In 1914 a tenth-acre fallow plat was sown. On this plat the stand was very thick and the growth was short, yielding at the rate of 13.4 bushels per acre. In 1915 three twentieth-acre plats were sown at the rate of 3, 4, and 5 pecks per acre on the barley scale. Under the favorable conditions which prevailed, the 3-peck and 4-peck rates yielded 27 bushels and the 5-peck rate 28.5 bushels per acre. The average yield of the three plats was 27.5 bushels per acre. When compared with spring barley or oats it is seen that spring emmer has not yielded as well as either of these crops during the 3-year period.

WINTER SPELT.

Only one variety of winter spelt has been tested at Archer, and that for only one year. On September 11, 1913, a tenth-acre plat was sown to Red Winter spelt. A good stand and a fair fall growth resulted, but the plants were entirely winterkilled. Spelt will probably never be an important crop in this area.

EXPERIMENTS WITH OATS.

WINTER OATS.

Only one variety of winter oats has been tested at Archer. On September 11, 1913, a tenth-acre fallow plat was sown to the Boswell Winter variety. A good stand and a fair fall growth resulted. The plants were all killed, however, during the ensuing winter, and winter oats have not since been grown. Oats are much less winter hardy than wheat and there is no likelihood that they will succeed as a winter crop in this section of the Great Plains area.

SPRING OATS.

The value of the oat crop in Wyoming is greater than that of any other cereal. A large proportion of the crop is grown under irrigation. Fairly good yields are obtained on the dry lands, however.

VARIETAL EXPERIMENT.

Fifteen varieties of spring oats have been tested at the Cheyenne Experiment Farm during 1913, 1914, and 1915. The annual and average yields of these varieties are shown in Table XVI. The oat varieties were grown in tenth-acre plats on breaking in 1913, in tenth-acre plats on fallow in 1914, and in duplicate twentieth-acre plats on double-disked corn ground in 1915.

In 1913 the seed bed was poor, the summer dry, and yields low. The Sixty-Day (C. I. No. 165) was the highest yielding variety, with 15.8 bushels per acre. In 1914 the seed bed was good, the summer dry, and yields low. The Kherson (C. I. No. 459) was the highest yielding variety, with 27.5 bushels per acre. In 1915 the seed bed was good, the spring and summer wet, and yields good. The Abundance (C. I. No. 731) was the highest yielding variety, with a yield of 52.4 bushels per acre. Oats do best in a cool, moist climate, which accounts for their better yields in 1915.

TABLE XVI.—*Annual and average yields of 15 varieties of spring oats grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C. I. No.	Yield per acre (bushels).			
		1913	1914	[a] 1915	3-year average.
Early:					
Sixty-Day	165	15.8	25.6	[b] 29.9	23.7
Kherson	459	[c] 12.5	[c] 27.5	[b] 29.3	23.1
Perm	170	13.5	24.5	[b] 26.5	21.5
Midseason:					
Swedish Select	134	10.0	26.7	52.1	29.6
Colorado No. 37	619	7.2	24.7	51.5	27.8
Ligowo	492	10.5	23.6	48.7	27.6
Silvermine	714	11.3	22.5	47.2	27.0
Abundance	731	7.5	20.3	52.4	26.7
Probsteier	495	12.2	22.5	45.0	26.5
Siberian	741	5.7	21.3	47.2	24.7
Lincoln	738	5.0	21.3	45.0	23.7
National	767	8.3	19.7	39.3	22.4
Montana	769	7.8	21.4	33.1	20.7
Banner	732	5.8	13.9	32.4	17.3
Late:					
Black Tartarian	768	7.8	18.8	41.5	22.5

[a] Average of 2 twentieth-acre plats.
[b] Damaged about 30 per cent by hail.
[c] Average of 6 tenth-acre check plats.

Oat varieties are usually grouped into early, midseason, and late varieties. In Table XVII are presented the average data on dates

FIG. 10.—A plat of oats on spring plowing on the Cheyenne Experiment Farm in 1915. (Photograph lent by the Office of Dry-Land Agriculture Investigations.)

of heading and maturity, height, weight per bushel, yield per acre, and ratio of grain to straw for the leading varieties of each group at Archer during the 3-year period, 1913 to 1915, inclusive.

The early varieties gave better yields in 1913 and 1914 than the midseason or late varieties. In 1915, however, the midseason varieties gave the highest yields, the early varieties being damaged by hail. The average yields for three years show the midseason varieties to be highest, the early varieties ranking second. The early varieties have matured about August 1 and the midseason and late varieties about August 14. The one late variety which was grown, Black Tartarian, usually ripened prematurely, so that the date recorded for it is earlier than normal. The early varieties averaged about 24 inches in height and the midseason and late varieties about 28 inches. The weights per bushel are for two years and are higher for the midseason and late varieties than for the early ones. However, all weights are above the legal standard of 32 pounds per bushel. The ratio of grain to straw is about 1 : 1 for the early varieties, while for the midseason varieties the ratio is about 1 : 1.35. A plat of early oats at the station is shown in figure 10. The yields from the leading varieties of each group are shown graphically in figure 11.

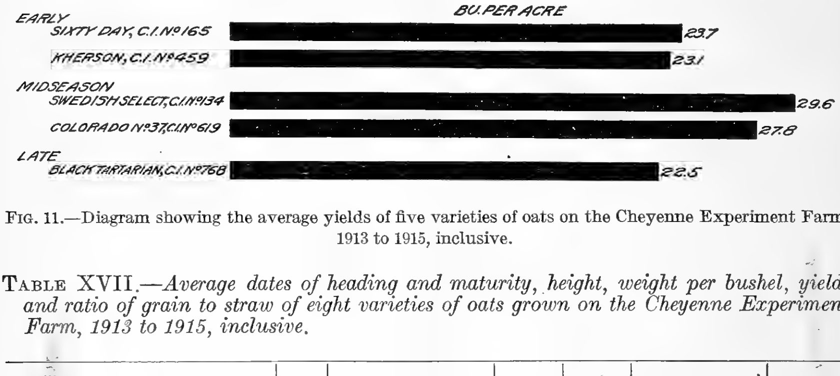

FIG. 11.—Diagram showing the average yields of five varieties of oats on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.

TABLE XVII.—*Average dates of heading and maturity, height, weight per bushel, yield, and ratio of grain to straw of eight varieties of oats grown on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.*

Group and variety.	C. I. No.	Date of—		Height.	Weight per bushel.[1]	Yield per acre.		Ratio, grain to straw.
		Heading.	Maturity.			Grain.	Straw.	
				Inches.	*Lbs.*	*Bush.*	*Lbs.*	
Early:								
Sixty-Day	165	July 7	Aug. 1	23	34.5	23.7	805	1 : 1.06
Kherson	459	...do...	July 31	24	33.5	23.1	715	1 : .97
Midseason:								
Swedish Select	134	July 20	Aug. 13	28	36.5	29.6	1,230	1 : 1.30
Colorado No. 37	619	July 21	Aug. 14	25	37.7	27.8	1,120	1 : 1.26
Ligowo	492	...do...	...do...	28	39.5	27.6	1,233	1 : 1.40
Silvermine	714	July 20	Aug. 12	28	37.2	27.0	1,063	1 : 1.23
Abundance	731	July 21	Aug. 16	28	37.0	26.7	1,065	1 : 1.25
Late:								
Black Tartarian	768	...do...	Aug. 14	26	38.2	22.5	967	1 : 1.34

[1] Average for two years only.

The leading varieties of oats to date are the Swedish Select (C. I. No. 134) and Colorado No. 37 (C. I. No. 619) of the midseason group, and the Kherson (C. I. No. 459) and Sixty-Day (C. I. No. 165) of the early group. The Kherson and Sixty-Day were the leading varieties in 1913 and 1914, but were reduced in yield by hail in 1915. It is believed that these two varieties and the Swedish Select are the best ones to grow in eastern Wyoming.

RATE-OF-SEEDING EXPERIMENT.

A rate-of-seeding test with Kherson oats has been conducted at the Cheyenne Experiment Farm during the 3-year period, 1913 to 1915, inclusive. Plats have been sown each year at the rate of 3, 4, 5, 6, and 7 pecks per acre. The annual and average yields obtained in this test are shown in Table XVIII. Poor yields were obtained in 1913. The highest yield (16.6 bushels) was obtained from the plat sown at the rate of 3 pecks. In 1914 fair yields were obtained, the highest (28.7 bushels) being from the 6-peck rate. In 1915 good yields were obtained, the highest (50.2 bushels) being produced from the 6-peck rate. The average yield from this test shows an increase in yield as the rate of seeding increased. Indications are that 5 or 6 pecks per acre is about the right quantity to sow in southeastern Wyoming.

TABLE XVIII.—*Annual and average yields of Kherson oats in a rate-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Rate of seeding.	Yield per acre.									
	1913		1914		1915		Average.			
							1913 to 1915.		1914 and 1915.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
3 pecks	16.6	480	24.7	610	a 36.0	1,560	25.7	883	30.3	1,085
4 pecks	15.0	420	26.2	610	a 41.2	1,470	27.4	833	33.7	1,040
5 pecks	14.5	475	25.9	770	a 46.5	1,540	28.9	928	36.2	1,155
6 pecks	13.6	648	28.7	740	b 50.2	1,770	30.8	1,053	39.4	1,255
7 pecks	....	....	26.4	875	b 50.0	1,510	....	....	38.2	1,192

a Damaged about 20 per cent by hail. b Damaged about 5 per cent by hail.

DATE-OF-SEEDING EXPERIMENT.

A date-of-seeding test with Kherson oats has been conducted on the Cheyenne Experiment Farm during the three years, 1913 to 1915, inclusive, Sowings have been made each year on April 15, May 1, and May 15. The annual and average yields obtained from this test are shown in Table XIX. In 1913 the May 1 sowing, in 1914 the April 15 sowing, and in 1915 the May 15 sowing gave the highest yields. Thus in the three years each date of seeding has given the highest yield once. The highest average yield, as shown in Table XIX, has resulted from the early seeding. Oats should be sown early, between April 15 and May 1

TABLE XIX.—*Annual and average yields of Kherson oats in a date-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Date of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
Apr. 15	7.5	260	28.7	730	[a] 34.0	1,120	23.4	703
May 1	8.3	270	26.2	610	[b] 33.4	1,150	22.6	677
May 15	7.0	638	22.5	670	[c] 34.9	1,660	21.4	989

[a] Damaged about 3 per cent by hail.
[b] Damaged about 35 per cent by hail.
[c] Damaged about 10 per cent by hail.

EXPERIMENTS WITH BARLEY.

WINTER BARLEY.

Only one variety of winter barley has been tested at Archer, and that in only one year. On September 11, 1913, a tenth-acre plat was sown to White Club barley. A good stand and a fair fall growth resulted. The crop was entirely killed during the ensuing winter.

Winter barley is not nearly as hardy as winter wheat, and it is hardly probable that it can be grown successfully in the Great Plains area.

SPRING BARLEY.

Spring barley is grown quite extensively in Wyoming, both in irrigated and dry-farmed sections.

VARIETAL EXPERIMENTS.

At Archer 14 varieties of spring barley have been tested in the three years, 1913, 1914, and 1915. The annual and average yields of these varieties are shown in Table XX. In 1913 the barley varieties were grown in single tenth-acre plats on fall-plowed breaking, in 1914 in single tenth-acre plats on spring-plowed fallow, and in 1915 in duplicate twentieth-acre plats on double-disked corn ground. Good stands have resulted each year. In 1913 the summer was dry and yields low. The White Smyrna (C. I. No. 658) yielded best, 10 bushels per acre. In 1914 the growing season was dry and the yields low, although somewhat higher than in 1913. The White Smyrna (C. I. No. 658) again was the highest in yield, producing 16.3 bushels per acre. In 1915 the spring and summer rainfall was high and the yields good. For the third successive year the White Smyrna produced the highest yield, 38.3 bushels per acre.

TABLE XX.—*Annual and average yields of 14 varieties of spring barley on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C. I. No.	Yield per acre (bushels).			
		1913	1914	1915	3-year average.
Two-rowed hulled:					
White Smyrna (Ouchac)	658	10.0	16.3	38.3	21.5
Hannchen	531	[a]9.6	[a]16.0	34.1	19.9
Hanna	24	8.8	10.8	32.0	17.2
Primus	532	8.9	8.3	33.9	17.0
Smyrna	195	5.7	9.6	30.6	15.3
Blackhull	878	[b]3.5	14.8	[b]22.7	13.7
Six-rowed hulled:					
Coast	690	6.6	14.4	41.2	20.7
Manchuria (Minn. No. 6)	638	6.6	11.8	33.5	17.3
Horsford	877	6.3	14.5	26.6	15.8
Manchuria (Minn. No. 105)	354	7.2	9.6	30.2	15.6
Gatami	575	4.4	15.5	23.7	14.5
Six-rowed naked:					
Black Hull-less	1106	9.8	7.5	27.8	15.0
Baku	709	5.2	8.3	23.3	12.3
Nepal	595	4.6	8.0	23.8	12.1

[a] Average of 6 tenth-acre check plats. [b] Damaged by hail.

In Table XXI the average data are given on dates of heading and maturity, height, weight per bushel, yield, and ratio of grain to straw for eight barley varieties grown during the three years, 1913 to 1915, inclusive, at the Cheyenne Experiment Farm.

TABLE XXI.—*Average dates of heading and maturity, height, weight per bushel, yield and ratio of grain to straw of eight varieties of spring barley grown on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.*

Group and variety.	C. I. No.	Dates of—		Height.	Weight per bushel.	Yield per acre.		Ratio, grain to straw.
		Heading.	Maturity.			Grain.	Straw.	
				Inches.	*Pounds.*	*Bush.*	*Pounds.*	
Two-rowed hulled:								
White Smyrna (Ouchac)	658	July 12	Aug. 1	18	47.5	21.5	987	1 : 0.96
Hannchen	531	July 14	Aug. 9	19	49.7	19.9	1,002	1 : 1.05
Hanna	24	July 22	Aug. 8	19	48.7	17.2	1,163	1 : 1.41
Six-rowed hulled:								
Coast	690	July 8	Aug. 2	21	40.0	20.7	1,052	1 : 1.01
Manchuria (Minn. No. 6)	638	July 12	Aug. 3	22	40.7	17.3	1,047	1 : 1.26
Horsford	877	July 9	Aug. 2	24	38.7	15.8	948	1 : 1.25
Manchuria (Minn. No. 105)	354	July 10	Aug. 3	21	40.5	15.7	1,095	1 : 1.45
Six-rowed naked:								
Black Hull-less	1106	July 14	Aug. 8	19	61.2	14.9	1,012	1 : 1.13

The varieties of the 6-rowed group were fully headed about July 10, and those of the 2-rowed group about July 15. The 6-rowed group reached maturity about August 2, and the 2-rowed group about August 8. There has been little difference in the height attained by the different varieties. The 2-rowed varieties have tested considerably higher in weight per bushel than the 6-rowed hulled varieties. The 2-rowed group has yielded higher than either of the other groups. All varieties have produced about the same quantity of straw per acre.

The average yields of the eight varieties are shown graphically in figure 12.

The White Smyrna (Ouchac, C. I. No. 658), a 2-rowed hulled variety, has given the highest annual and average yields. The Hannchen (C. I. No. 531), also a 2-rowed variety, has yielded well. In the 6-rowed hulled group, the Coast (C. I. No. 690) has been the highest yielding variety, with the Manchuria (Minn. No. 6, C. I No. 638) second. In the 6-rowed naked group, the Black Hull-less (C. I. No. 1106) has yielded quite well. There has been less than

FIG. 12.—Diagram showing the average yields of the five leading varieties of spring barley on the Cheyenne Experiment Farm, 1913 to 1915, inclusive.

1 bushel difference in the yields of the White Smyrna and the Coast, the two leading varieties. The Hannchen has also yielded well, since the yields here presented are averages from several check plats of this variety in 1913 and 1914.

RATE-OF-SEEDING EXPERIMENT.

A rate-of-seeding experiment with the Svanhals barley has been conducted at the Cheyenne Experiment Farm during the 3-year period, 1913 to 1915, inclusive. In 1913, plats were sown at the rates of 2, 3, 4, and 5 pecks per acre. In 1914 and 1915 sowings were made at the rates of 2, 3, 4, 5, 6, and 7 pecks. The annual and average yields obtained in the rate-of-seeding tests are shown in Table XXII.

TABLE XXII.—*Annual and average yields of the Svanhals barley in a rate-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Rate of seeding.	Yield per acre.									
	1913		1914		1915		Average.			
							1913 to 1915.		1914 and 1915.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Pounds.*	*Bush.*	*Pounds.*	*Bush.*	*Pounds.*	*Bush.*	*Pounds.*	*Bush.*	*Pounds.*
2 pecks	13.2	795	9.4	670	31.4	1,760	18.0	1,075	20.4	1,215
3 pecks	10.3	855	9.8	780	33.9	1,840	18.0	1,158	21.9	1,310
4 pecks	5.9	715	11.9	1,130	33.7	1,570	17.1	1,138	22.8	1,350
5 pecks	4.3	565	11.9	990	34.8	1,510	17.0	1,022	23.4	1,250
6 pecks	....	....	6.1	1,145	33.9	1,590	....	....	20.0	1,367
7 pecks	....	....	4.2	1,100	34.9	1,780	....	....	19.5	1,440

In 1913 the yields were low. The highest yield, 13.2 bushels per acre, was obtained from the 2-peck rate. In 1914 the highest yield, 11.9 bushels per acre, was obtained from the 4-peck and 5-peck rates. In 1915 the highest yield was 34.9 bushels per acre, obtained from the 7-peck rate, though the yield from the 5-peck rate was only slightly lower. The results to date show that a thin seeding of 2 to 4 pecks per acre has given the best average yields in the 3-year period.

DATE-OF-SEEDING EXPERIMENT.

A date-of-seeding experiment with the Svanhals barley has been conducted at the Cheyenne Experiment Farm during the 3-year period, 1913 to 1915, inclusive. Plats have been sown April 15, May 1, and May 15 each year. The annual and average yields obtained from this test are shown in Table XXIII.

TABLE XXIII.—*Annual and average yields of the Svanhals barley in a date-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Date of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
Apr. 15	9.9	610	14.4	760	31.2	1,580	18.5	983
May 1	12.0	835	10.5	705	34.3	1,650	18.9	1,063
May 15	7.6	675	5.7	795	40.3	1,980	17.8	1,150

Yields in 1913 and 1914 were low, with a slight advantage for the early seeding. In 1915 the yields were much higher, the May 15 seeding giving the highest yield, 40.3 bushels per acre. The average yields favor early seeding, between April 15 and May 1.

EXPERIMENTS WITH FLAX.

Flax is one of the common farm crops in eastern Wyoming, being grown quite extensively on the newly broken prairie. However, flax is not grown as extensively as results indicate that it should be.

VARIETAL EXPERIMENTS.

Fourteen varieties of flax have been grown on the Cheyenne Experiment Farm for a period of three years and two additional varieties for a period of two years. The annual and average yields obtained from these 16 varieties are shown in Table XXIV.

In 1913 the flax varieties were sown in tenth-acre plats on breaking at the rate of 15 pounds per acre. The seed was not well distributed by the drill, but fair stands resulted. The summer was rather dry, the precipitation in May and June being below normal. A fair growth was made and the yields ranged from 4.3 to 7.4 bushels per acre. The Select Russian (C. I. No. 3) gave the highest yield, 7.4 bushels.

TABLE XXIV.—*Annual and average yields of 16 varieties and strains of flax grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Variety.	C. I. No.	Yield per acre (bushels).				
		1913	1914	1915	Average.	
					1913 to 1915.	1914 and 1915.
Montana Common	6	7.0	5.6	17.6	10.1	11.6
Select Russian (N. Dak. No. 1215)	3	7.4	5.2	17.2	9.9	11.2
Fargo Common (N. Dak. No. 1133)	18	6.3	5.6	17.5	9.8	11.6
Russian (N. Dak. No. 155)	19	5.5	4.5	18.0	9.3	11.3
Russian (N. Dak. No. 155)	17	5.0	5.9	16.3	9.1	11.1
North Dakota Resistant No. 52	8	6.3	6.7	12.8	8.6	9.8
Russian (N. Dak. No. 1340)	5	7.0	4.5	14.0	8.5	9.3
Wyoming Common	63	[a] 5.0	[b] 4.9	15.3	8.4	10.1
Select Riga (N. Dak. No. 1214)	2	6.4	5.0	13.3	8.2	9.2
North Dakota No. 1221	16	5.4	5.5	13.5	8.1	9.5
Russian (N. Dak. No. 1329)	4	6.3	5.7	12.0	8.0	8.9
Select Russian	1	6.3	4.9	12.5	7.9	8.7
Blue Blossom	22	4.6	5.5	11.5	7.2	8.5
Primost (Minn. No. 25)	12	4.3	5.9	10.8	7.0	8.4
Idaho Common	15	....	4.4	18.5	....	11.4
North Dakota Resistant No. 114	13	....	3.8	12.5	....	8.1

[a] Average of 5 tenth-acre check plats. [b] Average of 7 tenth-acre check plats.

In 1914 the flax varieties were sown in tenth-acre plats on spring-plowed fallow land at the rate of 15 pounds per acre. Good stands were obtained. The precipitation in June and July was below normal and was poorly distributed. However, fair yields of flax were obtained. The yields ranged from 3.8 to 6.7 bushels per acre.

In 1915, 16 flax varieties were sown in duplicate twentieth-acre plats on double-disked corn ground at the rate of 15 pounds per acre. Good stands were obtained. The spring and summer rainfall was above normal. The growing season was considerably prolonged by the cool, wet weather. The growth was good and excellent yields were obtained, ranging from 10.8 to 18.5 bushels per acre. The 3-year average yield of 14 flax varieties ranges from 7 to 10.1 bushels per acre.

The four leading varieties and their average yields are: Montana Common (C. I. No. 6), 10.1 bushels; Select Russian (N. Dak. No. 1215, C. I. No. 3), 9.9 bushels; Fargo Common (N. Dak. No. 1133, C. I. No. 18), 9.8 bushels; and Russian (N. Dak. No. 155, C. I. No. 19), 9.3 bushels per acre.

Flax is a promising crop for eastern Wyoming, as shown by the results in the past three years. Flax growing need not be confined to newly broken land, as good results can also be obtained on old land if the seed bed is well prepared and kept free from weeds. Flax should not be grown continuously on the same land but in rotation with other crops, preferably after a clean-cultivated row crop. It is imperative that flax be grown in rotation with other crops, in order that loss from flax diseases may be reduced to the minimum.

RATE-OF-SEEDING EXPERIMENT.

Russian flax (C. I. No. 19) was grown at the Cheyenne Experiment Farm in a rate-of-seeding experiment during 1914 and 1915. Plats were sown each year at the rate of 10, 15, 20, and 25 pounds per acre. The annual and average yields obtained in this test are shown in Table XXV.

TABLE XXV.—*Annual and average yields of Russian flax (N. Dak. No. 155) grown in a rate-of-seeding test on the Cheyenne Experiment Farm in 1914 and 1915.*

Rate of seeding.	Yield per acre.					
	1914		1915		2-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
10 pounds	4.3	640	14.9	1,380	9.6	1,010
15 pounds	4.7	675	17.1	1,310	10.9	992
20 pounds	6.0	545	14.9	1,280	10.4	912
25 pounds	4.5	580	14.2	1,200	9.3	890

Low yields were obtained in 1914, due to summer drought. The highest yield was 6 bushels per acre, obtained from the 20-pound rate of seeding. Fallow land was used in this test in 1914.

In 1915 the sowings were made in duplicate twentieth-acre plats on double-disked corn ground. The summer was cool and wet and the yields were high. The highest yield was obtained from the plat sown at the rate of 15 pounds per acre.

Two years' results in the rate-of seeding test indicate that 15 to 20 pounds per acre is about the right quantity to sow.

DATE-OF-SEEDING EXPERIMENT.

A date-of-seeding experiment with flax has been in progress at the Cheyenne Experiment Farm for three years. In 1913, tenth-acre plats were sown on three different dates, May 1, May 15, and June 1. The highest yield was 7 bushels, obtained from the plat sown on June 1. In 1914, tenth-acre plats were sown on four dates, as shown in Table XXVI. The highest yield was 5.4 bushels, obtained from the June 1 sowing. In 1915, duplicate twentieth-acre plats were sown on four dates. The highest yield resulted from the sowing made on June 1. The land on which this experiment has been conducted received the same preparation as that on which the varieties were grown. The annual and average yields obtained are shown in Table XXVI.

There has been a progressive increase in yield from the early to the late seedings each year. The soil is rather late in warming up at Archer, and the early sowings have grown more slowly and required a longer period to reach maturity than the plats sown as late as June 1. However, the early sowings mature more uniformly than the late ones.

If the fall is wet, late-sown plats may continue green until destroyed by frost. This condition was observed in the vicinity of Archer in the fall of 1913. It will require years of testing to determine the best date to sow flax. Until more definite data are available it appears that sowing between May 15 and June 1 will be satisfactory.

TABLE XXVI.—*Annual and average yields of Select Russian flax (N. Dak. No. 1215) grown in a date-of-seeding test on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Date of seeding.	Yield per acre.							
	1913		1914		1915		3-year average.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
Apr. 15			2.7	310	9.7	1,440		
May 1	[a] 3.3	257	3.4	500	14.9	1,640	7.2	799
May 15	6.9	536	4.3	480	15.5	1,600	8.9	872
June 1	7.0	710	5.4	730	19.4	1,720	10.6	1,053

[a] Seeded too thick.

EXPERIMENTS WITH MINOR GRAIN CROPS.

The minor cereals, including proso, foxtail millet, grain sorghums, corn, and buckwheat, have been tested at the Cheyenne Experiment Farm during the 3-year period, 1913 to 1915, inclusive. Each of these cereals will be discussed briefly in the following paragraphs.

PROSO AND FOXTAIL MILLET.

Proso (broom-corn millet or hog millet) is grown for grain for feeding purposes, while foxtail millet is grown largely for hay. Proso is not grown extensively in eastern Wyoming, though it is fairly well adapted to the soil and climatic conditions prevailing in this district.

Eight prosos and two foxtail millets have been grown at the Cheyenne Experiment Farm during the 3-year period, 1913 to 1915, inclusive. The annual and average yields of the 10 millet varieties are shown in Table XXVII.

In 1913 the millets were grown in rows 132 feet long and spaced 3 feet apart on fall-plowed breaking. The summer was dry, but fair yields were obtained. In 1914 the millets were grown on fallow in twentieth-acre plats in rows 3 feet apart. The summer was dry and the yields obtained were low. In 1915 the millets were grown in twentieth-acre plats on double-disked corn ground. The yields obtained were low in spite of the better season.

The foxtail varieties have given higher average yields than the prosos. The proso yields have been materially reduced each year by shattering at and before harvest time. Birds are very fond of proso seed and have eaten large quantities before thrashing. A considerable acreage of foxtail millet is grown each year in Wyoming for hay. When grown for hay, 8 to 10 pounds of seed are required to sow an acre. Sowing is done with a grain drill equipped with a grass-seeder attachment. The millet is cut for hay when fully headed and before it begins to ripen.

TABLE XXVII.—*Annual and average yields of eight prosos and two foxtail millets grown on the Cheyenne Experiment Farm in 1913, 1914, and 1915.*

Group and variety.	C.I. No.	Yield per acre.				
		Grain (bushels).				3-year average of straw.
		1913	1914	1915	3-year average.	
Proso:						*Pounds.*
Red Turghai	31	22.3	7.7	9.6	13.2	1,023
Proso	113	23.2	10.9	0	11.4	2,583
Red Russian	11	10.7	6.6	11.6	9.6	728
White Ural	4	11.3	3.2	11.2	8.4	883
Black Voronezh	16	[a] 7.2	[b] 6.7	10.8	8.2	1,021
Tambov	13	[a] 12.0	[b] 5.2	6.0	7.7	755
Red Lump	65	10.9	3.2	6.0	6.7	603
Red Voronezh	60	7.2	1.8	6.0	5.0	613
Foxtail millet:						
Kursk (South Dakota No. 78)	......	14.8	16.3	[a] 29.5	20.2	1,613
Kursk (South Dakota No. 79)	......	8.9	10.9	[a] 26.9	15.6	2,532

[a] Average of two plats. [b] Average of three plats.

GRAIN SORGHUM.

Several of the earliest maturing varieties of grain sorghum have been tested each year. These varieties have been grown in 8-rod rows spaced 42 inches apart. The sorghums have been cultivated two or three times each season and kept free from weeds. Nearly all varieties have headed each year, but none has produced seed in sufficient quantity to warrant thrashing.

Manchu kaoliang (C. I. No. 261) and white kafir (C. I. No. 370) have been the earliest varieties tested. A few practically mature heads were obtained from each of these varieties in 1913 and 1914.

The results from the work with grain sorghum clearly show that this crop can not be grown for grain in eastern Wyoming. However, some of the varieties compare favorably with corn and sorgo in the production of roughage for stock. The milos and kafirs have considerably more foliage than the kaoliangs and should be grown when feed is wanted.

CORN.

A few varieties of field corn have been tested each year. Fair to good forage yields have been obtained each season, but in none of the three years has any variety fully matured. However, the Northwestern Dent, Brown County Yellow Dent, and Gehu Flint have produced mature grain each season, or at least mature enough to germinate if properly stored until the following spring.

Corn appears to be a very uncertain crop for grain at high elevations in eastern Wyoming, according to the three years' results obtained at Archer. It is probably the best crop to grow for silage or roughage, however.

BUCKWHEAT.

Buckwheat has been grown on the Cheyenne Experiment Farm in each of the three years. Two varieties have been tested, the Tartarian and the Mountain. Neither of these varieties appears to be adapted to conditions such as prevail at Archer. Buckwheat is unable to withstand drought, and hence all yields obtained have been low, except in 1915, a season of high rainfall. The Tartarian is about two weeks earlier than the Mountain variety. The yields in the three years (1913 to 1915) are as follows: Tartarian, 1, 1.3, and 8 bushels per acre; Mountain, 5, 3.5, and 16 bushels per acre, respectively. Buckwheat should apparently be grown in eastern Wyoming only in an experimental way.

SUMMARY.

The Cheyenne Experiment Farm is located on the plains of southeastern Wyoming at Archer, 8 miles east of Cheyenne. The elevation is almost exactly 6,000 feet. The station was established in July, 1912, and experimental work was begun in the fall of that year. The experiments reported herein, therefore, have continued three years.

The soil and climate are fairly typical of those of the district lying to the eastward. The results obtained are applicable to southeastern Wyoming and to adjacent small portions of Colorado, Nebraska, and South Dakota.

The soil is a light sandy loam, very productive when sufficient moisture is available. Heavier soils occur to some extent in other parts of the district.

The average annual precipitation at Cheyenne during the past 16 years has been 15.78 inches. The average seasonal precipitation (April to July, inclusive) during the same period has been 8.59 inches.

The evaporation from a free water surface during the growing season (April to July, inclusive) has been about 22.5 inches. The summers are rather short, without excessive heat. Hot winds do not occur. The average frost-free period is 125 days.

Experiments with wheat show that winter-wheat varieties have yielded higher than spring wheats in two years out of the three during which experiments have been conducted. The Ghirka Winter and Kharkof have been the highest yielding varieties.

Rate-of-seeding experiments with the Ghirka Winter and Turkey have given contradictory results during the three years. Four pecks to the acre seems to be the best rate to sow. Early sowing, during the first half of September, has given the highest average yields.

Spring wheats have yielded less than winter wheats. Durum wheats have yielded more than spring common wheats. The Beloturka and Kubanka are the highest yielding durum varieties. Among the spring common wheats, varieties of the Preston group have outyielded Fife and Bluestem wheats.

Experiments on the rate of seeding durum wheat are not conclusive. So far, 2 pecks of the Arnautka variety have given the highest average yields. Sowing early, about the middle of April, has given the highest average yields for spring common wheat.

In experiments with oats the early varieties, Kherson and Sixty-Day, have given the highest average yields in two of the three years. In 1915, a cool, wet year, midseason varieties were better. The Swedish Select has given the highest average yield in the 3-year period.

Kherson oats sown at the 6-peck rate yielded better than when sown at lower rates. Early seeding, about the middle of April, has given the best results.

Experiments with spring barley show that the White Smyrna and Hannchen, both 2-rowed bearded hulled varieties, have given the highest average yields.

The Svanhals barley sown at the rate of 2 pecks and 3 pecks per acre has yielded more than when sown at higher rates. The same variety has given the best yields when sown rather early, from the middle to the latter part of April.

Compared with wheat, the yields of spring oats and barley have been rather low. Winter oats and winter barley have been failures.

Varietal experiments with flax show Montana Common and Select Russian to be the best varieties. Sowing at the rate of 15 pounds per acre has given the highest average yield, and sowing about the first of June has proved better than earlier seedings.

Neither winter nor spring emmer has proved of value. Foxtail and proso millets have given only low yields. Buckwheat does not appear promising.

Grain sorghums and corn are promising forage crops for roughage or silage, but apparently have little or no value as grain crops.

The following varieties of the principal grain crops apparently are best for this district:

Winter wheat.—Ghirka and Kharkof or Turkey.
Spring wheat.—Kubanka, Erivan, Marquis.
Spring oats.—Kherson, Sixty-Day, Swedish Select.
Spring barley.—White Smyrna, Hannchen.
Flax.—Montana Common, Select Russian.

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Winter Wheat in Western South Dakota. Bureau of Plant Industry Circular 79.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 431

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 9, 1917

SACBROOD.

By G. F. White,
Expert, Engaged in the Investigation of Bee Diseases.

CONTENTS.

Introduction ... 1
Historical account ... 2
Name of the disease ... 4
Appearance of healthy brood at the age at which it dies of sacbrood ... 6
Symptoms of sacbrood ... 10
Cause of sacbrood ... 24
Weakening effect of sacbrood upon a colony ... 30
Amount of virus required to produce the disease, and the rapidity of its increase ... 31
Methods used in making experimental inoculations ... 32
Means for the destruction of the virus of sacbrood ... 34
Heating required to destroy sacbrood virus when suspended in water ... 34
Heating required to destroy sacbrood virus when suspended in glycerine ... 35
Heating required to destroy sacbrood virus when suspended in honey ... 36
Resistance of sacbrood virus to drying at room temperature ... 37
Resistance of sacbrood virus to direct sunlight when dry ... 38
Resistance of sacbrood virus to direct sunlight when suspended in water ... 39
Resistance of sacbrood virus to direct sunlight when suspended in honey ... 40
Length of time that sacbrood virus remains virulent in honey ... 40
Resistance of sacbrood virus to the presence of fermentative processes ... 41
Resistance of sacbrood virus to fermentation in diluted honey at outdoor temperature ... 42
Resistance of sacbrood virus to the presence of putrefactive processes ... 43
Resistance of sacbrood virus to carbolic acid ... 44
Modes of transmission of sacbrood ... 46
Diagnosis of sacbrood ... 48
Prognosis ... 49
Relation of these studies to the treatment of sacbrood ... 50
Summary and conclusions ... 52
Literature cited ... 53

INTRODUCTION.

Sacbrood is an infectious disease of the brood of bees. It is frequently encountered and has often been the cause of fear on the part of beekeepers through a suspicion that one of the more serious maladies—the foulbroods—was present.

The disease is more benign than malignant. It is insidious in its nature and somewhat transient in its character. The number of colonies that die as a direct result of sacbrood is comparatively small; the loss of individual bees from it, however, in the aggregate is enormous. The loss tends naturally to weaken the colony in which the disease is present, a fact which makes the disease one of great economic importance.

Until recently no laboratory study has been made of this disease. Circular No. 169, Bureau of Entomology, is a preliminary report on recent studies made by the writer. The present bulletin represents the results obtained from a continuation of these studies. In it are included only such results as it is believed can be applied by the beekeeper directly to his needs or as will be otherwise of particular interest to him.

HISTORICAL ACCOUNT.

There are a number of references in beekeeping literature to a disorder of the brood of bees which had been recognized by the presence of dead brood that was different from that dead of "foulbrood." It will be profitable to cite here a few of these articles:

Langstroth (1857) writes as follows:

> There are two kinds of foul-brood, one of which the Germans call the *dry* and the other the *moist* or *fœtid*. The dry appears to be only partial in its effects and not contagious, the brood simply dying and drying up in certain parts of the combs. The moist differs from the dry in this that the brood dies and speedily rots and softens, diffusing a noisome stench through the hive.

In this statement it will be seen that beekeepers had already recognized differences in the brood diseases which caused Langstroth to write that there were two kinds of "foulbrood." The kind referred to as "dry" foulbrood might easily have been sacbrood.

Doolittle (1881), following a description of "foulbrood," writes:

> We have been thus particular in describing the disease [foulbrood] so none can mistake it; and also because there is another disease similar, *called* foul brood, which is not foul brood. With this last-named, the caps to the cells have very much the same appearance as in the genuine, but the dead larva is of a grayish color, and instead of being stretched out at full length in the cell, it is drawn up in a more compact shape. After a time it so dries up that the bees remove it, and no harm seems to arise from it, only as there are a few larvæ that die here and there through the combs at different periods; sometimes never to appear again, and sometimes appearing with the next season; * * *.

Doolittle, therefore, as early as 1881, had also observed a brood disease which he says is similar to foulbrood and called foulbrood, but which is different from the genuine foulbrood. From his description one can readily believe that the disease which he says was not foulbrood was sacbrood.

Jones (1883), of Beeton, Ontario, Canada, writes the following:

> There is also another disease of the larvæ which is sometimes found both in Europe and America, which is more like foul brood than any of the above [chilled, starved, or neglected brood] and which frequently deceives those who we might claim should be good judges, but which, however, is not the genuine article. It is a dying of the brood both before and after it has been capped over. The appearance of this and the genuine is much the same during the earlier stages of their existence, but the former is usually removed by the bees and no further trouble ensues.

It will be noted that Jones also recognized that there was a disease that resembled somewhat the genuine foul brood, but was different from it, and that it was also different from chilled, starved, or neglected brood. Most likely the disorder referred to in his article was sacbrood.

Simmins (1887), writing from Rottingdean, England, points out the difference between "deadbrood" and foulbrood:

That foul brood is often confused with simple dead brood I am well aware. * * * But that every bee keeper may decide for himself without the aid of a microscope, which is the genuine foulbrood and which is not, I will show how I have always been able to detect the difference. With simple deadbrood, while some may appear like the foul disease, much of the older brood *dries up to a white cinder*, in many cases retaining its original form, which I have never found to occur when genuine foulbrood is present. Chilled brood can be distinguished from the more serious malady in like manner.

In addition to emphasizing the difference between "deadbrood" and "foulbrood," Simmins says that these two diseases are in turn to be differentiated from chilled brood. He adds the additional fact also that Cheshire had examined this "deadbrood" and failed to find any microscopic evidence of disease.

Cook (1904), under the heading "New Bee Disease," writes as follows:

In California and some other sections the brood dies without losing its form. We use the pin-head, and we draw forth a larva much discolored, often black, but not at all like the salvy mass that we see in foulbrood.

From his description, and from the fact that the disease is quite prevalent in California, it is very probable that the disorder mentioned by Cook is sacbrood.

A study of this "dead brood" recognized by the beekeepers as being different from foulbrood was begun by the writer in New York State in 1902, under the direction of Dr. V. A. Moore. In a brief report on the work (1904) the following is found:

The beekeepers are sustaining a loss from a diseased condition in their apiaries which they are diagnosing as "pickled brood." The larvæ usually die late in the larval stage. The most of them are found on end in the cell, the head frequently blackened and the body of a watery granular consistency. * * * The results of the examinations showed that *Aspergillus pollinis* was not found. Further investigations must be made before any conclusion can be drawn as to the real cause of this trouble.

It will be observed from this quotation that the so-called pickled brood did not conform to the description of pickled brood and could not therefore be the condition which had called forth the description of and the name, "pickled brood" (see p. 4).

Burri (1906), of Switzerland, writes:

Dead brood, said to have been black brood, I have occasionally met with in my investigations. It occurred in the older larvæ, and showed a gray to blackish coloration, partially drying the larvæ until mummified. These larvæ of the black-brood type gave a negative result both in microscopic examination and in the usual bacteriological culture experiments. Bacteria seem to take no part in this disease, and so far as I have come in contact with black brood, I have been able to reach no certain opinion as to its cause. [Translation.]

It is very probable that the disorder encountered by Burri, which was free from bacteria, was sacbrood. Out of 25 samples examined between 1903 and 1905, he found four samples containing this disease alone, while in a few of the samples the disorder was accompanied by one of the other brood diseases.

Kursteiner (1910), of Switzerland, gives a summary of all samples examined by Burri and himself from 1903 to 1909. Out of 360 samples of suspected disease examined, 94 were diagnosed as "dead brood free from bacteria." These were probably samples of sacbrood. As shown by his later reports, Kursteiner has continued to find this disease in the examination of suspected samples.

The foregoing references to the literature show that beekeepers in different countries had been observing dead brood in their apiaries which was unlike brood dead of "foulbrood." On this point all of the observers practically agreed. No name had been given to the disorder.

NAME OF THE DISEASE.

Before 1912, very little definite information concerning this somewhat mysterious disorder of the brood had been obtained. After discovering its cause and determining its true nature, the writer (1913) used the name "sacbrood" to designate it. The name was coined to suggest the saclike appearance of the dead larvæ in this disease at the time they are most frequently seen by the beekeeper.

The fact should here be emphasized that sacbrood is not a new disease. It is only the knowledge concerning the disease and its name that is of recent origin. It is far better, and in all probability much more accurate, to think of sacbrood as a disease which has affected bees longer than history records the keeping of bees by man. The disease, therefore, has been collecting its toll of death for centuries, often unawares to the beekeeper. Simply knowing that there is such a disease should not be the cause of any additional anxiety concerning its losses. On the other hand, less fear should be experienced, since by knowing of it hope may be entertained that the losses resulting from it may be reduced.

PICKLED BROOD.

The term "pickled brood" was introduced into beekeeping literature 20 years ago (1896), by William R. Howard of Texas. The condition which he described under this term he declared was caused by a fungus to which he gave the name *Aspergillus pollini.* In a second article (1898) he writes that pupæ and adult bees, as well as the larvæ, are attacked by the disease, stating his belief that the disease in adult bees had been diagnosed as paralysis. Technically, therefore, the term "pickled brood" refers to an infectious disorder of bees affecting both the brood and adult bees and caused by a specific fungus, *Aspergillus pollini.*

It was particularly unfortunate that these articles on pickled brood should have appeared at the time they did, as through them some beekeepers have been led to the mistaken belief that the brood disease, which they had so long observed as being similar to "foulbrood," but differing from it, had been described in his articles as pickled brood.

Whether such a disease (pickled brood) does exist, can not be definitely stated. It may be said, however, that it probably does not. The writer has not encountered such a disorder during his study on the bee diseases. He believes that if the condition is present it certainly has not attracted the attention of beekeepers to any great extent. It can safely be advised, therefore, that all fear of losses from such a possible condition should be dispelled, at least until the disease is met with again.

It would seem that the name "pickled brood" is being used among beekeepers at present in a very general sense. Root (1913) writes:

> The name pickled brood has been applied to almost any form of dead brood that was not foul brood. In a rather general way, it seems to cover, then, any form of brood that is dead from some natural causes not related to disease of any sort.

This quotation suggests that a number of conditions are most likely included under the term "pickled brood" as it is popularly used. Brood dead of starvation and that found dead before capping and not dead of an infectious disease seem to be referred to especially by the name.

Beekeepers sending samples of disease to the laboratory have been asked the question: "What disease do you suspect?" In the replies received more than one disease was sometimes suggested as being suspected. Out of 189 replies received from beekeepers sending samples of sacbrood, European foulbrood was suggested in 55 replies, pickled brood in 39, foulbrood in 19, blackbrood in 15, poisoned brood in 7, chilled brood in 5, starved brood in 6, American foulbrood in 13, dead brood in 3, neglected brood in 1, scalded brood in 1, suffocated brood in 1, and in 24 cases the reply was: "Don't know." These replies show that beekeepers generally had not learned to recognize the disorder which is now called sacbrood by any one name.

It is natural to suppose that sacbrood would have been one of the conditions occasionally referred to under the term "pickled brood."

As sacbrood has been proved, however, to be a distinct disease and different from all other disorders, naturally it is incorrect to use the terms "sacbrood" and "pickled brood" synonymously, either in the popular or in the technical sense.[1]

APPEARANCE OF HEALTHY BROOD AT THE AGE AT WHICH IT DIES OF SACBROOD.

By comparing the appearance of healthy brood with that of brood dead of a disease, both the description and the recognition of the symptoms of the disease are often materially aided. Before discussing the symptoms of sacbrood, therefore, a description of the healthy brood at the age at which it dies of sacbrood will be given. In this description the same method will be used and similar terms employed as will be found in the description of the symptoms of the disease.

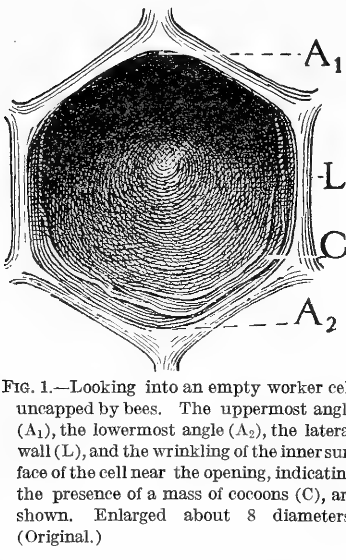


FIG. 1.—Looking into an empty worker cell uncapped by bees. The uppermost angle (A_1), the lowermost angle (A_2), the lateral wall (L), and the wrinkling of the inner surface of the cell near the opening, indicating the presence of a mass of cocoons (C), are shown. Enlarged about 8 diameters. (Original.)

It will be recalled by those who are at all familiar with healthy comb in which brood is being reared that the brood is arranged in such a way that capped and uncapped areas occur alternately and in more or less semicircular fashion. Practically all cells in the uncapped areas will be without caps while practically all in the capped areas will be capped.

Since the brood that dies of sacbrood, with but few exceptions, does so in capped cells, a description of such brood involves the form, size, and position of these cells.

A cell (figs. 1 and 2) may be described as having six side walls, a bottom or base, and a cap. (The cap has been removed by the bees from the cells from which these figures were drawn.) In general the six side walls are rectangular and equal. These walls form six equal obtuse angles within the cell (fig. 1). The angle which is uppermost in the cell (A_1) is formed by two sides which together may be termed the roof of the cell. The angle which is lowermost (figs. 1 and 2, A_2) is formed by two sides which with equal propriety may together be termed the floor of the cell (fig. 2, F). When a cell is cut along its long axis

[1] For the purpose of an explanation for those who may have learned to refer to sacbrood by the term "pickled brood," it might be felt advisable by some to continue for a while in some way a reference to the latter term. In such an event, the expression "so-called pickled brood" is suggested as being more nearly accurate than the term "pickled brood."

the cut surface of the older ones shows the presence of a varying number of old cocoons (fig. 2, C). Near the mouth of the cell on the side walls (figs. 1 and 2, C) will often be noted a wrinkling of the surface. This wrinkling is caused by the presence of old cocoons. The two remaining walls are parallel and will be referred to as the lateral walls (fig. 1, L). The bottom is concave on the inside. The cap is also concave on the inside, making it convex on the outside.

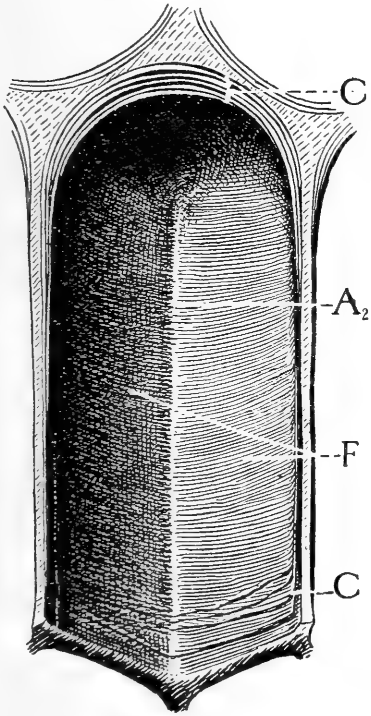


FIG. 2.—Empty worker cell cut in half along the long axis of the cell, showing cocoons (C) at the base and near the mouth of the cell, and the lowermost angle (A_2) formed by the two walls which constitute the floor (F) of the cell. Enlarged about 8 diameters. (Original.)

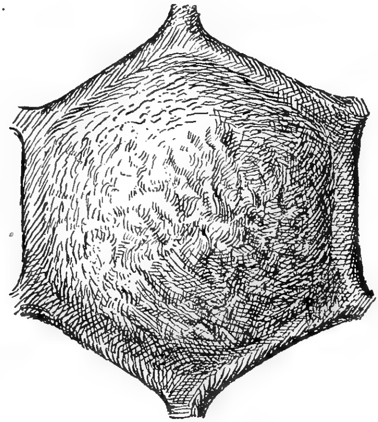


FIG. 3.—End view of cell capped. The cap is convex, being recently constructed. (Original.)

When freshly constructed the surface of the cap (fig. 3) is smooth and and entire and shows considerable convexity. Later, not infrequently it is found to be less convex and somewhat irregular. The cap should remain normally for the most part entire (fig. 8). While this is the rule, there are exceptions to it. The beekeeper is familiar with the appearance which suggests that it had not been entirely completed (fig. 11; Pl. II, *b*).

The long axis of the cell is nearly horizontal, the bottom of the cell being normally only slightly lower than the mouth. The long axis measures approximately one-half inch, while the perpendicular distance between any two diametrically opposite side walls is approximately one-fifth of an inch. The side walls are each approximately one-tenth of an inch wide. It is in such a cell, then, that the brood of the age at which it dies of sacbrood is found.

APPEARANCE OF A HEALTHY LARVA AT THE AGE AT WHICH IT DIES OF SACBROOD.

The symptoms which differentiate sacbrood from the other brood diseases are to be found primarily in the post-mortem appearances of the larvæ dead of the disease. As an aid in interpreting the description of these appearances a description of the healthy larvæ is first made.

Larvæ[1] that die of sacbrood do so almost invariably after capping and at some time during the four days just preceding the change in form of the maturing bee to that of a true pupa.

During the first two days of this prepupal period the larva moves about more or less in the cell and spins a cocoon. It is then comparatively quiet for about two days, lying on its dorsal side and ex-

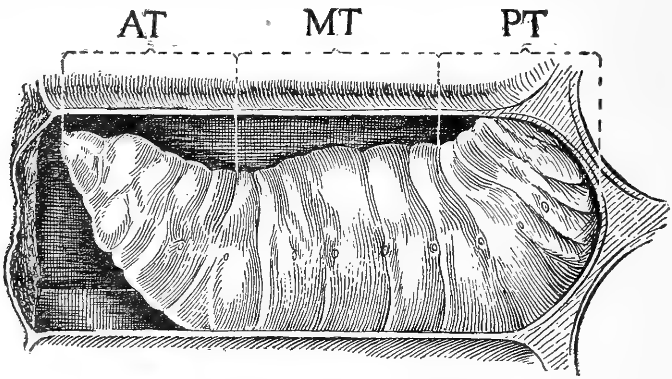


FIG. 4.—Lateral view of healthy worker larva showing the normal position within the cell. For convenience of description the length is divided into thirds—anterior third (AT), middle third (MT) and posterior third (PT). Enlarged about 8 diameters. (Original.)

tended lengthwise in the cell. At the close of this two-day period of rest, as a result of the metamorphosis going on, the larva changes very rapidly to a true pupa, assuming the outward form of an adult bee.

Although many larvæ die of sacbrood during the first two days cr active period, of the 4-day prepupal period, by far the greater number of deaths occur during the last two days, the period of rest. A healthy larva at this resting period of its development is chosen, therefore, for description. As dead worker larvæ are the ones usually encountered in sacbrood and the ones almost invariably chosen in discussing the symptoms of the disease, the worker larva is here described.

The normal larva lies extended in the cell (fig. 4) on its dorsal side, motionless, and with its head pointing toward the mouth of the cell. Its posterior or caudal end lies upon the bottom of the cell,

[1] As beekeepers usually refer to the brood at this age as "larvæ," the term is used here to designate the developing bee at this stage of its growth.

while its extreme anterior or cephalic end extends almost to the cap and roof. The length of the larva is approximately one-half inch, being nearly that of the cell. Its two lateral sides cover about one-half each of the two lateral walls. The width of the larva is approximately one-fifth of an inch, being the distance between the two lateral walls of the cell.

The dorsal portion of the larva lies against the floor of the cell, being more or less convex from side to side and also from end to end. Its ventral surface is convex from side to side, and is, generally speaking, concave from end to end. Considerable empty space is found between the larva and the roof of the cell. The spiracles are visible. The glistening appearance, characteristic of a larva before capping, very largely disappears after capping. Although larvæ at this age might be thought of as white, they are in fact more or less bluish white in color. It is possible to remove a healthy larva at this age from the cell without rupturing the body wall, but care is required in doing so.

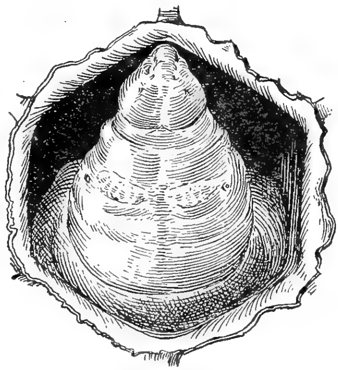


FIG. 5.—End view of healthy worker larva in normal position in the cell. Cap torn and turned aside with forceps. Enlarged about 8 diameters. (Original.)

For purposes of description it is convenient to divide the length of the larva into three parts. These may be denominated the anterior (AT), middle (MT), and posterior thirds (PT).

Anterior third.—On removing the cap from a cell the anterior cone-shaped portion of the larva is seen (fig. 5; Pl. II, *g*). The apex of this cone-shaped third is directed upward toward the angle in the roof of the cell, but is not in contact with the roof or the cap. Transverse segmental markings are to be seen. Along a portion of the median dorsal line there is frequently to be observed a narrow transparent area. A cross section of this third is circular in outline. The anterior third passes rather abruptly into the middle third. At their juncture on each lateral side, owing to a rapid increase in the width of the larva at this point, there is presented the appearance of a "shoulder."

Middle third.—This third (figs. 6 and 4; Pl. II, *m*) lies with its dorsal portion upon the floor of the cell, its axis being nearly horizontal. The ventral surface is convex from side to side, and is considerably below the roof of the cell. This upper surface is crossed from side to side by well-marked furrows and ridges representing segments of the larva. These furrows and ridges produce a deeply notched appearance at the lateral margins. In some of the segments a transverse trachea may be seen appearing as a very fine, scarcely perceptible, white line. Sometimes there may be seen a narrow area along the median line of the ventral surface that is more nearly transparent than the remaining portion of the surface. This area may extend slightly into the anterior and posterior thirds. It is similar in appearance to the one on the dorsal side, but less distinct. A cross section of this third is slightly elliptical in outline. The middle third passes more or less gradually into the posterior third. The juncture on the ventral surface is indicated by a wide angle formed by the ventral surfaces of these two thirds.

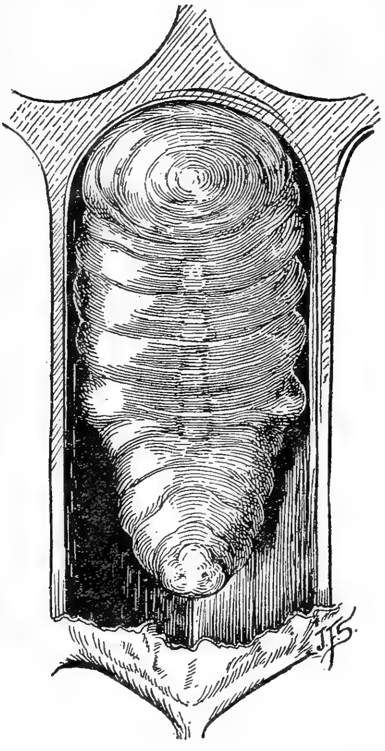


FIG. 6.—Healthy larva and cell viewed from above and at an angle. (Original.)

Posterior third.—In form the posterior third (figs. 6 and 4) is an imperfect cone, the axis of which is directed somewhat upward from the horizontal. This third occupies the bottom portion of the cavity of the cell. Its dorsal surface lies upon the bottom wall, with the extreme caudal end of the larva extending to the roof of the cell (fig. 4). The third is marked off into segments by ridges and furrows similar to, but less regular than, those of the middle third.

TISSUES OF A HEALTHY LARVA AT THE AGE AT WHICH IT DIES OF SACBROOD.

Upon removing a larva in the late larval stage and puncturing its body wall lightly, a clear fluid almost water-like in appearance flows out. This fluid consists chiefly of larval blood. By heating it, or by treating it with any one of a number of different reagents, a coagulum is formed in it. Upon rupturing the body wall sufficiently, the tissues of the larva flow out as a semiliquid mass. The more nearly solid portion of the mass appears almost white. This portion is suspended in a thin liquid, chiefly blood of the larva. A microscopic examination shows that the cellular elements of the mass are chiefly fat cells. Many fat globules suspended in the liquid tend to give it a milky appearance.

SYMPTOMS OF SACBROOD.

The condition of a colony depends naturally upon the condition of the individual bees of which it is composed. In the matter of diseases in practical apiculture the beekeeper is interested primarily in the colony as a whole, and not in individual bees. Therefore, in describing the symptoms of a bee disease, the colony as a whole should be considered as the unit for description, and not the individual bee. A symptom of disease manifested by an individual bee, broadly considered, is, in fact, also a colony symptom. The symptoms of sacbrood as described in this paper are, therefore, those evidences of disease that are manifested by a colony affected by the disease.

It has been found that sacbrood can be produced in a healthy colony by feeding it a suspension in sirup of crushed larvæ dead of the disease. With sacbrood thus produced in experimental colonies the symptoms of the disease have been studied, and the description of these symptoms given here is based chiefly upon observations made in these experimental studies. The facts thus obtained are in accord with those observed in numerous samples of the disease sent by beekeepers from various localities in the United States for diagnosis. They are in accord, furthermore, with the symptoms as they have been observed in colonies in which the disease has appeared, not through experimental inoculation but naturally.

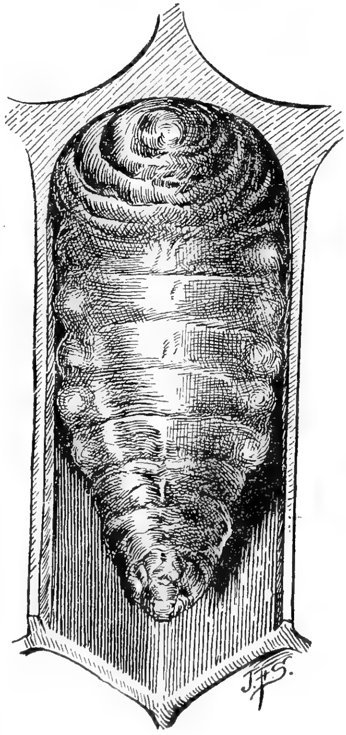


FIG. 7.—Larva dead of sacbrood lying in the cell as viewed from above and at an angle. It may have been dead a month. Cap of cell removed by bees. Enlarged about 8 diameters. (Original.)

The symptoms of sacbrood which would ordinarily be observed through a more or less casual examination of the disease will first be considered. It must be remembered that the brood is susceptible to the disease, but that the adult bees are not.

SYMPTOMS AS OBSERVED FROM A CASUAL EXAMINATION.

The presence of dead brood is usually the first symptom observed. An irregularity in the appearance of the brood nest (Pl. I, figs. 1 and 2; Pl. IV) frequently attracts attention early in the examination. The strength of a colony in which the disease is present is often not noticeably diminished. Should a large amount of the brood become affected, however, the colony naturally becomes weakened thereby, the loss in strength soon becoming appreciable. Brood that dies of the disease does so almost invariably in capped cells, but before the pupal stage is reached. It is rare to find a pupa dead of sacbrood (Pl. II, *zz*). The larvæ that die (fig. 7) are found lying extended lengthwise with the dorsal side on the floor of the cell. They may be found in capped (fig. 8) cells or in cells which have been uncapped (fig. 9), as bees often remove the caps from cells containing dead larvæ. Caps that are not removed are more often entire, yet not infrequently they are found to have been punctured by the bees. Usually only one puncture is found in a cap (Pl. II, *d*), but there may be two (fig. 10) or even more (Pl. II, *f*). The punctures vary in size, sometimes approximating that of a pinhead, although usually smaller, and are often irregular in outline. Sometimes a cap (fig. 11, Pl. II, *b*) has a hole through it which suggests by its position and uniform circumference that it has never been completed. Through such an opening (fig. 11; Pl. II, *e*) or through one of the larger punctures the dead larva may be seen within the cell.

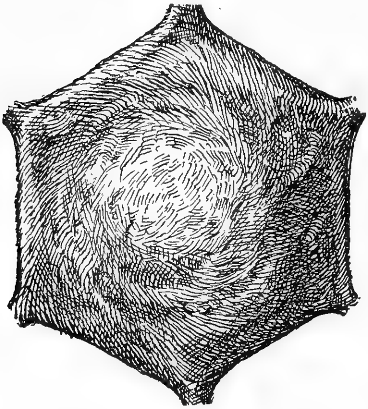


Fig. 8.—End view of capped cell which contains a larva dead of sacbrood, being similar to the one shown in figure 9. The cap here is not different from a cap of the same age over a healthy larva. (Original.)

A larva recently dead of sacbrood is slightly yellow. The color in a few days changes to brown. The shade deepens as the process of decay continues, until it appears in some instances almost black. Occasionally for a time during the process of decay the remains present a grayish appearance.

In sacbrood, during the process of decay, the body wall of the dead larva (figs. 7 and 9) toughens, permitting the easy removal of the remains intact from the cell. The content of the saclike remains, during a certain period of its decay, is watery and granular in appearance. Much of the time the form of the remains is quite similar to that of a healthy larva. If the dead larva is not removed, its surface, through evaporation of its watery content, becomes wrinkled, distorting its form. Further drying results in the formation of the

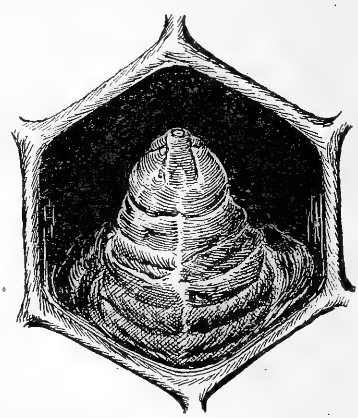


Fig. 9.—Looking into a cell containing a larva dead of sacbrood. The stage of decay is about the same as in figure 8. (Original.)

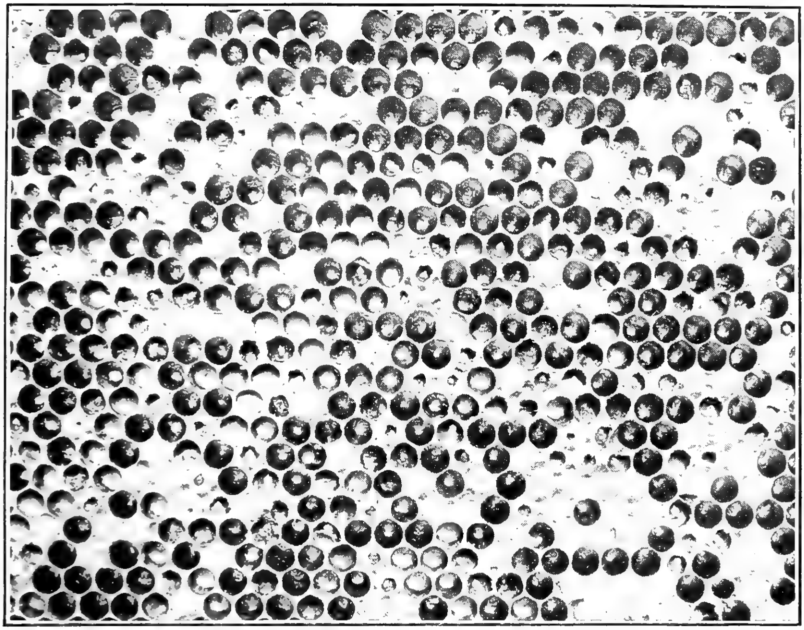


FIG. 1.—MARKED SACBROOD INFECTION. SIZE SLIGHTLY LESS THAN NATURAL. (ORIGINAL.)

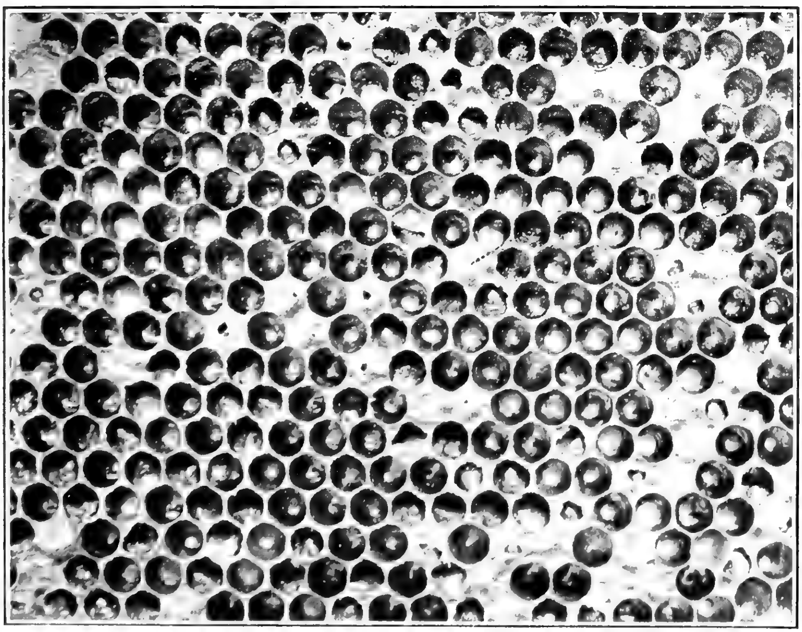
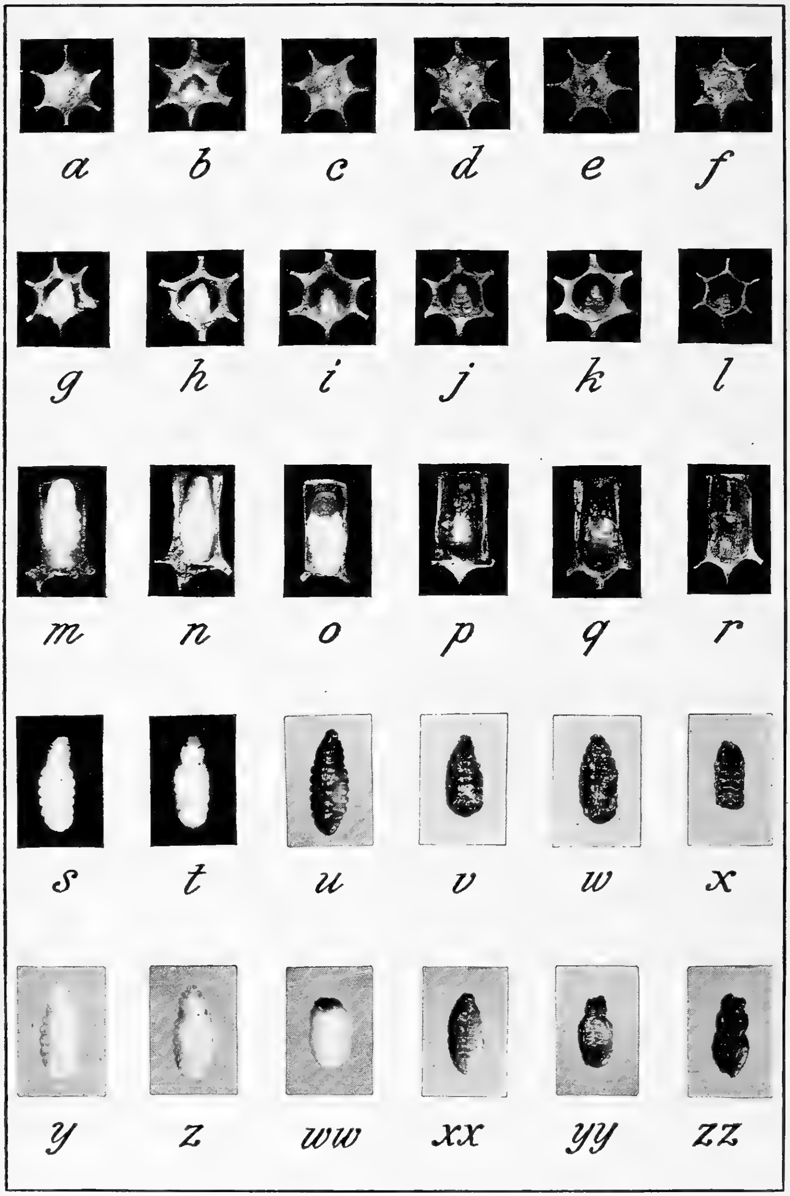


FIG. 2.—HEAVY SACBROOD INFECTION, SHOWING A NUMBER OF DIFFERENT STAGES OF DECAY OF LARVÆ. EGGS, YOUNG LARVÆ IN DIFFERENT STAGES OF DEVELOPMENT, AND DISEASED LARVÆ IN SAME AREA. NATURAL SIZE. (ORIGINAL.)

SACBROOD PRODUCED BY EXPERIMENTAL INOCULATION.



COMPARISON OF A HEALTHY LARVA AND THE REMAINS OF LARVÆ DEAD OF SACBROOD.

a, A cap of a healthy larva; *b*, *c*, *d*, *e*, and *f*, caps over larvæ in first, second, third, fourth, and fifth stages of decay, respectively; *g*, a healthy larva, end view; *h*, *i*, *j*, *k*, and *l*, an end view of the five stages of decay; *m*, a healthy larva viewed from above; *n*, *o*, *p*, *q*, and *r*, corresponding view of the five stages of decay; *s* and *y*, healthy larva removed from the cell; *t*, *u*, *v*, *w*, and *z*, larval remains in different stages of decay removed from the cell; *ww*, a larva recently dead of sacbrood with the anterior third removed by the bees; *x*, a scale removed from the cell; *xx*, larval remains from which a small portion has been removed by bees; *yy*, almost a pupa; *zz*, a pupa dead of sacbrood which had only recently transformed. (Original.)

"scale" (figs. 22, 23; Pl. II, *l*, *r*, and *x*). This scale is not adherent to the cell wall.

In sacbrood the brood combs may be said to have no odor. Larvæ undergoing later stages of decay in the disease, however, when crushed in a mass and held close to the nostrils are found to possess a disagreeable odor.

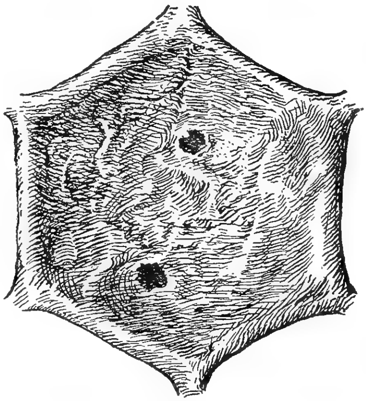


FIG. 10.—Cap of cell containing the remains of a larva dead of sacbrood. The cap is slightly sunken and bears two perforations made by the bees. (Original.)

From a superficial or casual examination alone of a case of sacbrood it may be mistaken for some other abnormal condition of the brood. A careful study of the post-mortem appearances of larvæ dead of the disease, however, will make it possible to avoid any such confusion. A more careful study of the dead larvæ is therefore justified.

APPEARANCE OF LARVÆ DEAD OF SACBROOD.

No signs in a larva dying of sacbrood have yet been discovered by which the exact time of death may be determined. As the larvæ in this disease usually die during the time when they are motionless, lack of movement can not be used as an early sign of death. In this description it is assumed that the larva is dead if it shows a change in color from bluish-white to yellowish or indications of a change from the normal turgidity to a condition of flaccidity.

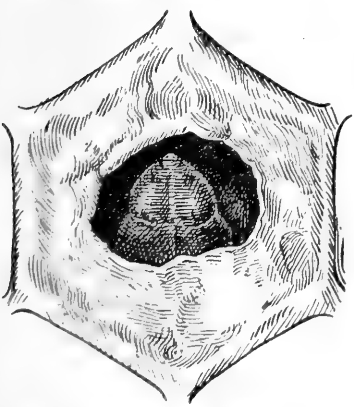


FIG. 11.—End view of cell containing a larva dead of sacbrood, with a cap which has the appearance of never having been completed. (Original.)

The appearance of a larva dead of sacbrood varies from day to day, changing gradually from that of a living healthy larva to that of the dried residue—the scale. A description that would be correct for a dead larva on one day, therefore, may and probably would be incorrect for the same larva on the following day. Moreover, all larvæ dead of the disease do not undergo the same change in appearance, causing another considerable range of variation. For convenience of description, this gradual and continual change in appearance is here considered in five more or less arbitrary stages. As the same plan will be followed and similar terms will be used in describing these stages as were employed in the description of a healthy larva of the same age, the interpretation of the description will be aided if the appearance of a healthy larva as described above is borne in mind.

First Stage.

Uncapping a larva showing the first symptoms of the disease, it will be observed that it has assumed a slightly yellowish appearance.

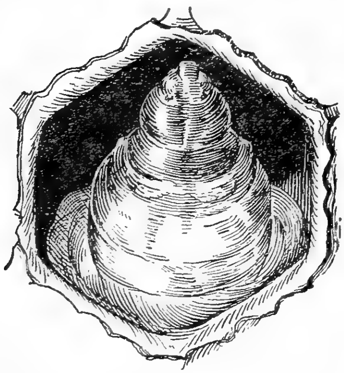


Fig. 12.—First stage: Larva showing first symptoms of sacbrood and presenting the dorsal view of the anterior third. Cap removed artificially. (Original.)

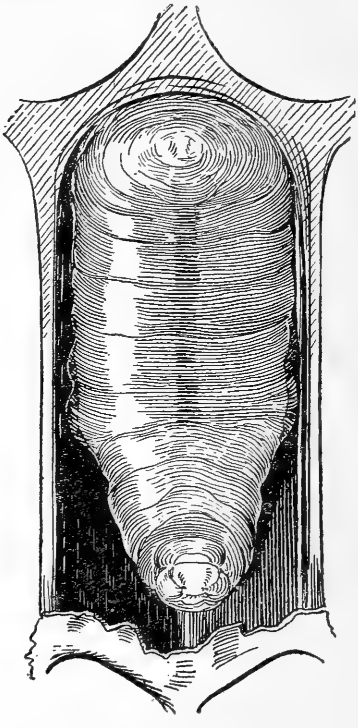


Fig. 13.—First stage: Ventral view of larva dead of sacbrood as seen from above and at an angle, giving a ventral view of all three thirds. Cap torn across. (Original.)

This shade deepens somewhat during the stage, but does not become a deep yellow.

Anterior third.—The lateral margins and extreme cephalic end of the anterior third (fig. 12; Pl. II, *b*, *h*) may have assumed, and frequently do assume, a more or less transparent appearance (represented in the figure by shading). The position and the surface markings of the anterior third are approximately those of the normal larva. When a change in the position is observed, however, the extreme anterior end of the larva—the apex of this cone-like third—having settled somewhat, does not approach so near the roof of the cell as does that of a healthy larva. It is sometimes found also that this cone-like third is deflected more or less to one side or the other.

Middle and posterior thirds.—The changes from the normal that have taken place in these two thirds are similar and can, therefore, be described together. The yellowish tint is here observed. The transverse ridges and furrows are still well marked (fig. 13). The transverse tracheæ under slight magnification may be distinctly seen. The narrow, somewhat transparent area present along the ventral median line of the healthy larva is still to be seen in this stage of the decay. The lateral and posterior margins are still deeply notched and are frequently found to appear quite transparent. This appearance is due to a watery looking fluid beneath the cuticular portion of the body wall.

Sometimes only the remnant of a larva (fig. 14; Pl. II, *ww*) dead of sacbrood is found in the cell. Such remnants vary in size. The

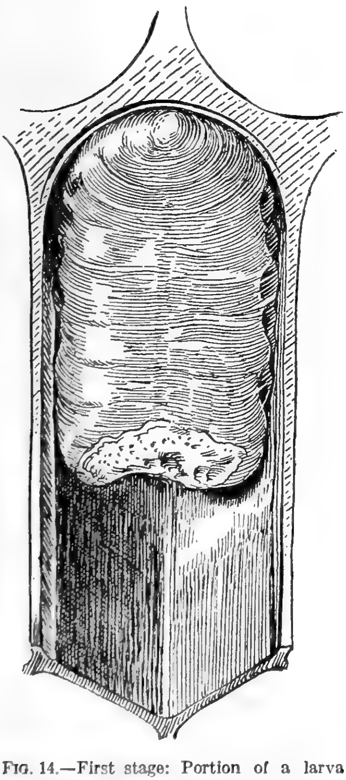


FIG. 14.—First stage: Portion of a larva dead of sacbrood, showing a more or less transverse roughened surface from which the bees have removed a portion of the larva piecemeal. (Original.)

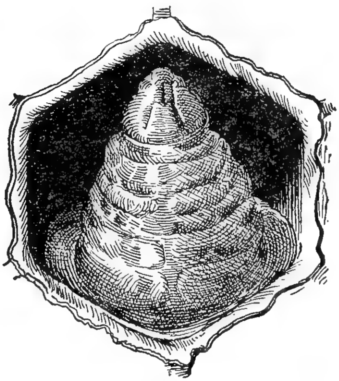


FIG. 15.—Second stage: Dorsal view of anterior third of a larva dead of sacbrood. (Original.)

surface left from the removal of tissues is somewhat roughened, indicating that the removed portion has been taken away piecemeal, and is more or less transverse to the larva.

Consistency of the larva in the first stage.—The cuticular portion of the body wall, which chiefly constitutes the sac that characterizes the disease sacbrood, is less easily broken at this time than in the healthy larva. When the body wall is broken the tissues of the larva, which constitute the contents of the sac, flow out. This fluid tissue mass is less milky in appearance than that from a normal larva. The granular character of the contents of the sac which is marked in later stages of decay is already in evidence. By microscopic examination the granular appearance is found to be due chiefly to fat cells.

Condition of the virus in the first stage.—When larvæ of this stage are crushed, suspended in sirup, and fed to healthy bees, a large amount of sacbrood is readily produced, showing that the larval remains in this stage are particularly infectious. This is an important fact, as it is the stage of decay at which the larva is frequently removed piecemeal from the cell.

SECOND STAGE.

The color of the decaying larva has changed from the yellowish hue of the first stage to a brownish tint. The yellow, however, has not yet in all cases entirely disappeared.

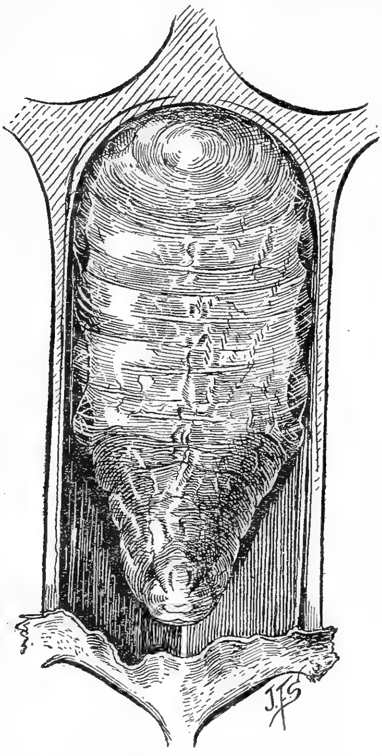


FIG. 16.—Second stage: Larva dead of sacbrood, ventral view. (Original.)

FIG. 17.—Third stage: Dorsal view of anterior third of larva dead of sacbrood. (Original.)

Anterior third.—The shade of brown is deeper in the anterior third (fig. 15; Pl. II, *i*) as a rule than in the other two thirds. On the ventral surface of the anterior third there are sometimes present minute, very dark, nearly black areas, appearing little more than mere points. Upon dissecting away the molt skin, these areas are found to be associated with the developing head and thoracic appendages of the bee. The position of the anterior third in this stage has changed only slightly from that observed in the preceding one. The apex is farther from the roof of the cell (Pl. II, *i*). The deflection is more marked and is seen in a greater number of larvæ. The surface markings have not changed materially.

Middle and posterior thirds.—The changes that have occurred in each of these two thirds are still similar and can, therefore, again be described together.

The ventral surface of these two thirds (fig. 16, Pl. II, *o*) is less convex from side to side. The ridges and furrows, representing the segments, are less pronounced. The lateral margins are still deeply notched. The prominent angle seen on the ventral side of a healthy larva, at the juncture of the middle and posterior thirds, has given place to a wider one in this stage of decay. The clear subcuticular fluid frequently observed at the lateral and posterior margins of larvæ dead of this disease is here increased in quantity.

Consistency of the contents of the sac.—The cuticular sac is now more readily observed and less easily broken. The decaying contents consist of a more or less granular-appearing mass suspended in a watery appearing fluid, the mass possessing a slightly brownish hue. The microscopic examination shows that the granular appearance is due to the presence of decaying tissue cells, chiefly fat cells, which are changing slowly as the decay of the larva goes on.

Condition of the virus.—The results of inoculations show that the remains of larvæ at this stage of decay are still in some instances infectious. The amount of infection produced when such larvæ are used in making inoculations is very much less, however, than when larvæ in the first stage are used.

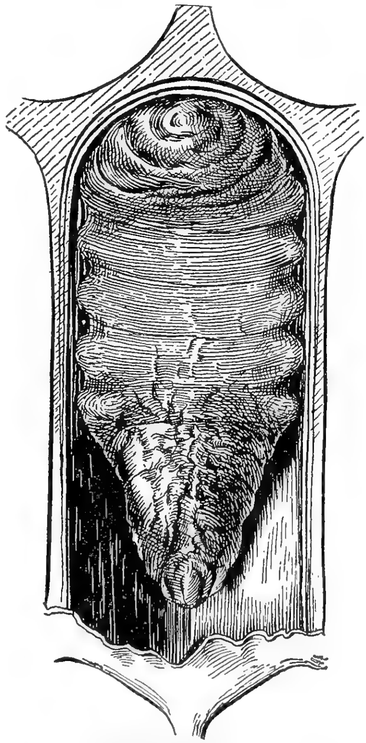


Fig. 18.—Third stage: Larva dead of sacbrood, ventral view. (Original.)

Third Stage.

The color of the dead larva of this stage is quite brown, that of the anterior third being a deeper shade than that of the other two thirds. An indication that the remains are drying is observed in the wrinkling of the surface that is beginning to be in evidence.

Anterior third.—The color of the anterior third is a deep brown. This third still preserves its conelike form (figs. 17 and 9; Pl. II, *j*), the distance of the apex from the roof of the cell being still further increased. This may equal one-fourth or more of the diameter of the mouth of the cell. The surface markings are still quite similar to those of a healthy larva with the exception that evidences of drying are present.

Middle third.—While the color of the middle third is similar to and often approaches in its shade that of the anterior, very frequently it is considerably lighter. The ventral surface of this third (figs. 18 and 7) is less convex from side to side than in the preceding stage, and the segmental markings, while still plainly visible, are less pronounced. The notches along the lateral margins are also less pronounced.

Posterior third.—The color of the posterior third (figs. 18 and 7; Pl. II, *p*) equals or exceeds in depth of shade that of the middle third and sometimes equals that of the anterior third. The surface markings are still pronounced and much resemble those of the normal larva.

That the watery content of the sac is being lessened through evaporation is evidenced by the diminution of the quantity of the watery-

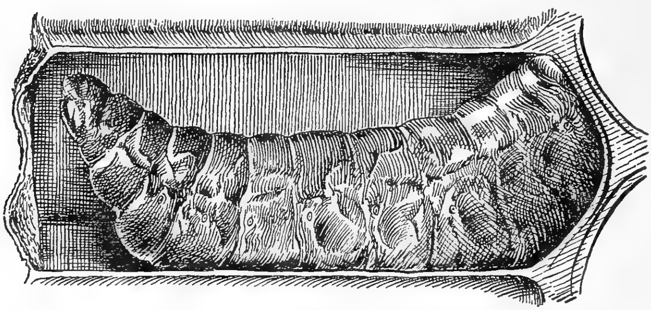


FIG. 19.—Third stage: Larva dead of sacbrood, lateral view. (Original.)

appearing substance seen at the lateral margins of the middle and posterior thirds and by the wrinkling of the cuticular sac. These wrinkles are small and numerous.

The lateral view of the larva in the third stage (fig. 19) shows that it still maintains, in a general way, the form and markings of the normal larva (fig. 4). The turgidity is gone, although the position in the cell is very much as it is in the healthy larva.

Consistency of the sac and its contents.—It is the appearance of the remains of the larva in the third stage of the decay that best characterizes the disease, sacbrood. The cuticular sac is now quite tough, permitting the removal of the larva from the cell with considerable ease and with little danger of its being torn. The content of the sac is a granular mass, brownish in color and suspended in a comparatively small quantity of a more or less clear watery-appearing fluid. Upon microscopic examination the mass is found to consist of decaying tissues, chiefly fat cells.

Condition of the virus in the third stage.—When the larval remains in this stage of decay are crushed and fed in sirup to healthy colonies no sacbrood is produced, indicating that the dead larvæ at this stage are not infectious. The status of the virus in this stage is not definitely known, but the facts thus far obtained indicate that it is probably dead.

FOURTH STAGE.

The brown color of the larval remains has further deepened, the anterior third being much darker as a rule than the other two-thirds. The marked evidence of drying now present might be said to characterize this stage.

Anterior third.—The color is a very deep brown, often appearing almost black. As a result of drying, the apex of this conelike third

FIG. 20.—Fourth stage: Remains of larva dead of sacbrood. (Original.)

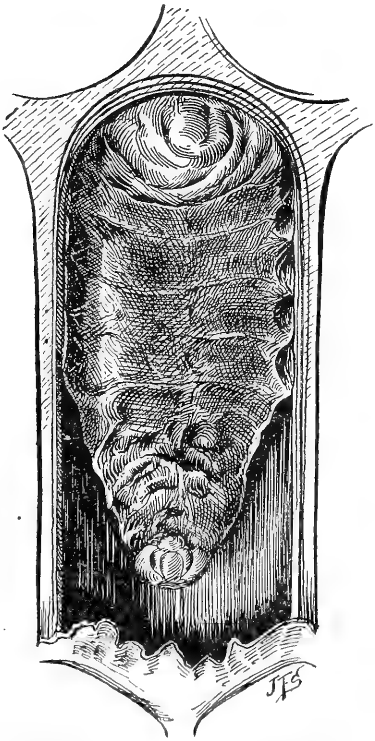


FIG. 21.—Fourth stage: Remains of larva dead of sacbrood, ventral view. (Original.)

is often nearer the roof of the cell in this stage than in the preceding one. As a result it has also been drawn inward from the mouth of the cell. The surface markings seen in the normal larva are in this stage (fig. 20; Pl. II, *k*) of decay almost obliterated through the wrinkling of the surface, due to drying.

Middle third.—This third is decidedly brown, but lighter in shade than the anterior third. The ventral surface (fig. 21; Pl. II, *q*) is slightly concave from side to side. The segmental markings are still to be seen, but are not at all prominent. The notched lateral margins extend upon the side walls of the cell. The subcuticular fluid so noticeable in some of the earlier stages has disappeared through evaporation. The effect of drying is very noticeable, causing a marked wrinkling of the surface.

Posterior third.—The posterior third (Pl. II, *q*) may or may not be darker than the middle third, but it is not darker than the anterior third. The effect of the drying on this third is quite perceptible also. The surface markings and notched margin of the normal larva are still indicated in the decaying remains, but are much less pronounced. The subcuticular fluid is no longer in evidence.

Consistency of the contents of the sac.—Upon tearing the sac, the contents are found to be less fluid than in preceding stages. The decaying tissue mass is still granular in appearance. As the drying proceeds further the contents of the sac become pastelike in consistency.

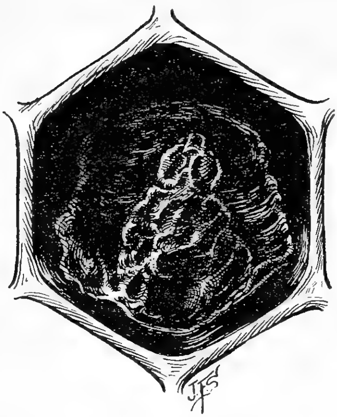


FIG. 22.—Fifth stage: Scale, or larval remains, in sacbrood as seen on looking into the cell. (Original.)

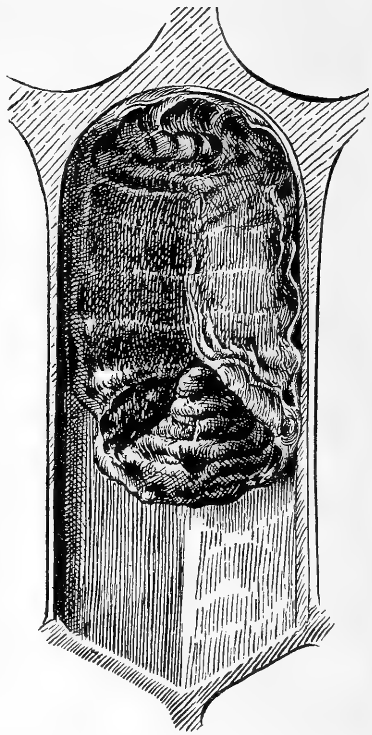


FIG. 23.—Fifth stage: Scale, or larval remains, in sacbrood viewed at an angle from above. (Original.)

Condition of the virus in the fourth stage.—As in the preceding stage, the larval remains in the fourth stage do not seem to be infectious.

FIFTH STAGE.

The dead larva in this last stage has lost by evaporation all of its moisture, leaving the dry, mummylike remains known as the "scale."

Anterior third.—The anterior third (fig. 22; Pl. II, *l*) through drying is retracted from the mouth of the cell, with the apex drawn still deeper into the cell and raised toward its roof. This third is greatly wrinkled, and, being of a very dark-brown color, presents often an almost black appearance.

Middle third.—The middle third (fig. 23; Pl. II, *r*), is deeply concave from side to side and may show remnants of the segmental markings of the larva. The surface is often roughened through drying. Sometimes both longitudinal and transverse tracheæ are plainly visible. The margin frequently presents a wavy outline corresponding to the original furrows and ridges of the lateral margin of the larva.

Posterior third.—The posterior third (figs. 23 and 24) extends upon the bottom of the cell, but does not completely cover it. A lateral view of the scale (fig. 24) shows that it is turned upward anteriorly and drawn somewhat toward the bottom of the cell. The ventral surface is concave, often roughened, and directed somewhat forward. This margin, like that of the middle third, has a tendency toward being irregular.

The scale.—The scale can easily be removed intact from the cell. (Pl. II, *x*.) Indeed, when very dry, many of them can be shaken from the brood comb. When out of the cell, they vary markedly in appearance. The anterior third is of a deeper brown than the the other two thirds as a rule. The dorsal side of the middle and

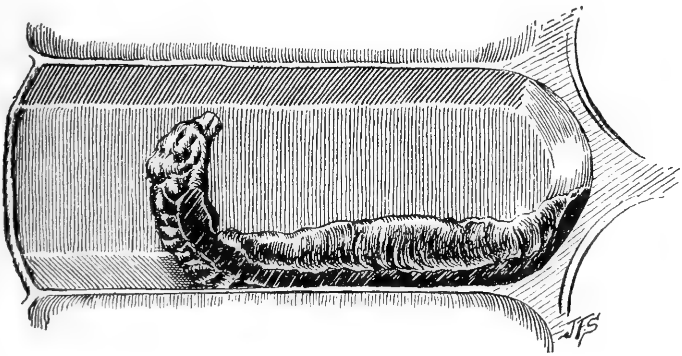


FIG. 24.—Scale, or larval remains, in position in cell cut lengthwise, lateral view. (Original.)

posterior thirds is shaped to conform to the floor of the cell, being in general convex, with a surface that is smooth and polished. The margin is thin and wavy. The anterior third and the lateral sides of the middle and posterior thirds being turned upward, the ventral surface being concave, and the posterior side being convex, the scale in general presents a boatlike appearance and could be styled "gondola-shaped." This general form of the scale has been referred to by beekeepers as being that of a Chinaman's shoe. When completely dry, the scale is brittle and may easily be ground to a powder.

Condition of the virus in the scale.—The scales in sacbrood, when fed to healthy bees, have shown no evidence of being infectious.

The length of time that dead larvæ are permitted by the bees to remain in the cells before they are removed varies. They may be removed soon after death, they may remain until or after they have become a dry scale, or they may be removed at any intervening stage in their decay. Not infrequently they are permitted to remain to or through the stage described above as the third stage (figs. 7, 9, 17, and 18; Pl. II *j*, *p*). That the dead larvæ are allowed to remain in the cells often for weeks is in part the cause of the irregularity observed in the appearance of the brood combs (p. 11). (Pls. I, IV.)

APPEARANCE OF THE TISSUES OF A LARVA DEAD OF SACBROOD.

The gross appearance of a larva during its decay after death from sacbrood has just been described. The saclike appearance of the remains, with its subcuticular watery-like fluid and its granular content, can better be interpreted by knowing something of the microscopic structure of the dead larva.

A section through a larva (fig. 25, A) dead of sacbrood shows that the fat tissue constitutes the greater portion of the bulk of the body. The fat cells (FC) are comparatively large. In the prepared section when considerably magnified (C) they are seen to be irregular in outline, with an irregular-shaped nucleus (Nu). Bodies stained black, more or less spherical in form and varying in size, are found in them. The presence of these cells is the chief cause for the granular appearance of the contents of larvæ dead of sacbrood. This appearance has often been observed by beekeepers and is a well-recognized symptom of sacbrood.

In the section (A) may be seen a molt skin (C_2), which is at a considerable distance from the hypodermis (Hyp). Another cuticula (C_1) is already quite well formed and lies near the hypodermis. Between these two cuticulæ (C_2 and C_1) during the earlier stages of decay there is a considerable space ("intercuticular space") (IS). This space is filled with a watery-looking fluid. That the fluid is not water, but that it is of such a nature that a coagulum is formed in it during the preparation of the tissues for study, is shown by the presence of a coagulum in the sections.

The body (B, A) wall of the larva is composed of the cuticula (C_1), the hypodermis (Hyp) and the basement membrane (BM). The hypodermal cells may be present in the mass content of the larval remains. These cells are comparatively small. Similar ones are to be found in the tracheal walls (Tra). These cells, however, make up only a small portion of the contents of the sac.

There are many other cellular elements to be found in the decaying mass of larval tissues, some of which contribute to this granular appearance. Among these are the œnocytes (Oe), cells (D) larger than the fat cells, but comparatively few in number. These are found among the fat cells, especially in the ventral half of the body. The œnocytes in the prepared tissues are irregular in outline, having a nucleus regular in outline. The cytoplasm is uniformly granular and does not contain the black staining bodies found in the fat cells (C).

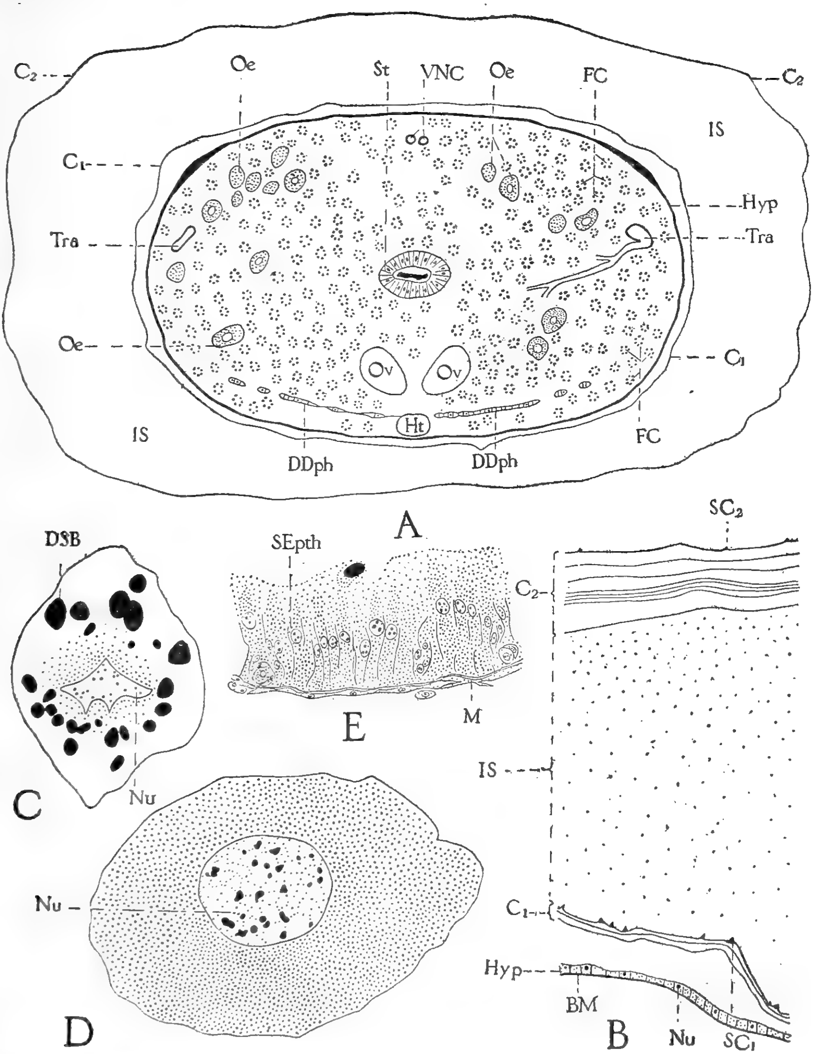


FIG. 25.—The tissues of a worker larva after being dead of sacbrood about one week. A, cross section, semidiagrammatic, of the abdomen in the region of the ovaries, showing a recently cast cuticula, or molt skin (C_2), a newly formed cuticula (C_1), the hypodermis (Hyp), the stomach (St), the ovaries (Ov), the heart (Ht), the ventral nerve cord (VNC), the dorsal diaphragm (DDph), tracheæ (Tra), œnocytes (Oe), and fat cells (FC). Between the cuticula C_2 and the cuticula C_1 is a considerable intercuticular space (IS). B represents the body wall in this pathological condition, showing the cuticula C_2 and the cuticula C_1, both bearing spines (SC_2 and SC_1), and the intercuticular space (IS) in which is found evidence of a coagulum formed from the fluid filling the space by the action of the fixing fluids. The remainder of the body wall, the hypodermis (Hyp), and the basement membrane (BM) are also shown. C, fat cell with irregular outline, irregular nucleus (Nu), and deep staining bodies (DSB). D, œnocyte with uniformly staining cytoplasm, and with a nucleus (Nu) having a uniform outline. E, a portion of the stomach wall showing the epithelium (SEpth) during metamorphosis, it being at this time quite columnar in type, and the musculature (M). (Original.)

The molt skin (C_2) is probably the one that is shed normally about three days after the larva is capped. The cuticula (C_1), already quite well formed, is probably the one which normally would have entered into the formation of the molt skin that is cast at the time the larva or semipupa changes to a pupa. The molt skin (C_2) constitutes for the most part the sac which is seen to inclose the decaying larval mass in sacbrood, the cuticula (C_1) probably assisting somewhat at times. The presence of the subcuticular fluid is made more intelligible by these facts. Larvæ dying of sacbrood at an earlier or later period in their development will present an appearance varying somewhat from that just described.

Contrasted with the stomach (midintestine or midgut) of a feeding larva, the stomach (A, St) of a larva at the age at which it dies of sacbrood is small. The cells lining the wall of the organ vary considerably in size and shape, depending upon the exact time at which death takes place. In contrast to the low cells of the stomach wall in younger larvæ, the cells (E, SEpth) at this later period are much elongated. These cells would also at times be found in the decaying granular mass present in the larval remains.

The various organs of the body contribute to the cellular content of the decaying larval mass. At the period at which the larva dies of sacbrood, the cellular changes accompanying metamorphosis are particularly marked. This condition introduces various cellular elements into the decaying larval mass.

The granular mass from the larval remains in sacbrood is, therefore, a composite affair. Upon examining the mass microscopically, it will be found that the granular appearance is due for the most part to fat cells suspended in a liquid. The liquid portion seems to be chiefly blood of the larva, or, at least, derived from the blood, although augmented most probably by other liquids of the larva and possibly by a liquefaction of some of the tissues present. The granular mass suspended in a watery fluid, as a symptom of sacbrood, is by these facts rendered more easily understood.

CAUSE OF SACBROOD.

Doolittle (1881), Jones (1883), Simmins (1887), Root (1892 and 1896), Cook (1902), Dadant (1906), and others through their writings have pointed out the fact that there are losses sustained from sacbrood. There has been no consensus of opinion, however, as to the infectiousness of the disease. On this point Dadant (1906) writes:

> Whatever may be the cause of this disease (so-called Pickled Brood), and although it is to a certain extent contagious, it often passes off without treatment. But, as colonies may be entirely ruined by it, it ought not to be neglected.

In the quotation Dadant expresses the belief that the disease is an infectious one. This view has been proved by recent studies to be the correct one. Since the disease is one of a somewhat transient nature, often subsiding and disappearing quickly without treatment, and is quite different in many ways from the foulbroods, it is not strange that some writers should have held that it is not infectious.

PREDISPOSING CAUSES.

Beekeepers have known for many years certain facts concerning the predisposing causes of sacbrood. Recent studies have added others relative to sex, age, race, climatic conditions, season, and food as possible predisposing factors in the causation of the disease.

Age.—The results of the studies suggest that adult bees are not directly susceptible to the disease. Pupæ are rarely affected (Pl. II, *zz*). If one succumbs to the disease, it is quite soon after transformation from the larval stage. Primarily it is the larvæ that are susceptible. When a larva dies of the disease, it does so almost invariably after capping, and usually during the 2-day period immediately preceding the time for the change to a pupa.

Sex.—Worker and drone larvæ may become infected. Queen larvæ apparently are also susceptible, although this point has not yet been completely demonstrated.

Race.—No complete immunity against sacbrood has yet been found to exist in any race of bees commonly kept in America. That one race is less susceptible to the disease than another may be said to be probable, although the extent of such immunity has not been established.

The question: "What race of bees is there in the diseased colony?" was asked beekeepers sending samples of diseased brood. Out of 140 replies received from those sending sacbrood samples, 53 reported hybrids, 49 reported Italians, 21 reported blacks, and 17 reported Italian hybrids. These replies show that the bees commonly kept by American beekeepers are susceptible, although their relative susceptibility is not shown.

The bees which have been inoculated in the experimental work on sacbrood have been largely Italians or mixed with Italian blood. Blacks have also been used. No complete immunity was observed in any colony inoculated. That the blacks are more susceptible than strains having Italian blood in them is suggested by some of the results. Facts concerning the problem of immunity as relating to bees are yet altogether too meager to justify more definite statements.

Climate.—Historial evidence strongly suggests that sacbrood is found in Germany (Langstroth, 1857), England (Simmins, 1887), and Switzerland (Burri, 1906). Beuhne (1913) reports its presence in Australia, and Bahr (1915) has encountered a brood disorder among bees in Denmark which he finds is neither of the foul broods. He had examined 10 samples of it but had not studied it further. He says it may be sacbrood.

About 400 cases of sacbrood have been diagnosed by Dr. A. H. McCray and the writer among the samples of brood received for examination at the Bureau of Entomology. A few of these were obtained from Canada. Whether the disease occurs in tropical climates or the coldest climates in which bees are kept has not yet been completely established.

The mountains and coast plain of the eastern United States, the plains of the Mississippi Valley and the mountains, plateaus, and coast plain of the western portion of the country have contributed to the number of samples examined. It occurs in the South and the North.

Its occurrence in such widely different localities is proof that sacbrood is of such a nature that it can appear under widely different climatic conditions. The relative frequency of the disease, furthermore, is not materially different in the different sections of the country. It must be said, however, that the extent, if any, to which the disease is affected by climate has not yet been determined.

The practical import of these observations regarding climate, of particular interest here, is that the presence of sacbrood in any region can not be attributed entirely to the prevailing climatic conditions.

Season.—It has long been known that sacbrood appears most often and in the greatest severity during the spring of the year. As is shown by the results obtained in the diagnosis of it in the laboratory, the disease may appear at any season of the year at which brood is being reared. In the inoculation experiments sacbrood has been produced with ease from early spring to October 21. While it is thus shown that the brood is susceptible to sacbrood at all seasons, various factors together cause the disease to occur with greater frequency during the spring.

Food.—Before it was known that sacbrood is an infectious disease the quantity or quality of food was not infrequently mentioned by beekeepers as being the cause of the disease. Since a filterable virus has been shown to be the exciting cause of the disease, it is left to be considered whether food is a predisposing cause. The distribution of the disease mentioned above, under the heading "Climate," here again serves a useful purpose. Since it occurs in such a wide range of localities, wherein the food and water used by the bees vary as greatly almost as is possible in the United States, the conclusion may be drawn that its occurrence is not dependent upon food of any restricted character. Furthermore, sacbrood is found in colonies having an abundant supply of food, as well as in colonies having a scarcity. It has been produced experimentally in colonies under equally varying conditions in regard to the quantity of food.

While it is possible that the quantity or quality of food may influence somewhat the course of the disease in the colony, the rôle played by food in the causation of sacbrood must be slight, if indeed it contributes at all appreciably to it. Practically, therefore, for the present it may be considered that neither the quality nor quantity of food predisposes to this disease.

EXCITING CAUSE OF SACBROOD.

That sacbrood is an infectious disease was demonstrated by the writer (1913) through experiments performed during the summer of 1912. This was done by feeding to healthy colonies the crushed tissues of larvæ dead of sacbrood, suspended in sugar sirup. The experiments were performed under various conditions, and it was found that the disease could be produced at will, demonstrating thereby that it was actually an infectious one.

In the crushed larval mass no microorganisms were found either microscopically or culturally to which the infection could be attributed, although the experiments had proved that the larva dead of the disease did contain the infecting agent. This led to the next step in the investigation, which was to determine whether the virus was so small that it had not been observed, and whether its nature would permit its passage through a filter. The first filter used for this purpose was the Berkefeld.

The process by which the filtration is done is briefly this: Larvæ which have been dead of sacbrood only a few days are picked from the brood comb and crushed. The crushed mass is added to water in the proportion of 1 part larval mass to 10 parts water. A higher dilution may be used. This aqueous suspension is allowed to stand for some hours, preferably overnight. To remove the fragments of the larval tissues still remaining, the suspension is filtered, using filter paper. The filtrate thus obtained is then filtered by the use of the Berkefeld filter[1] (fig. 26) properly prepared. The filtering in the case of the coarser filters especially can be done through gravity alone.

To determine whether any visible microorganisms are present in this last filtrate, it is examined microscopically and culturally. When found to be apparently free from such microorganisms, a quantity of it may be added to sirup and the mixture fed to healthy colo-

[1] The Berkefeld filter consists of a compact material (infusorial earth) in the form of a cylinder. A glass mantel (A) in which is fixed the filter forms a cup for holding the fluid to be filtered. Having filtered the aqueous suspension of crushed sacbrood larvæ through paper, the filtrate is then filtered by allowing it to pass through the walls of the Berkefeld cylinder (B). The filtrate from this filtration is collected into a sterile flask (F) through a glass tube (D) with its rubber connection (C). In filtering in this instance gravity is the only force used.

nies. When all this is properly done, sacbrood will appear in the inoculated colonies. This shows that the virus [1] of this disease, to a

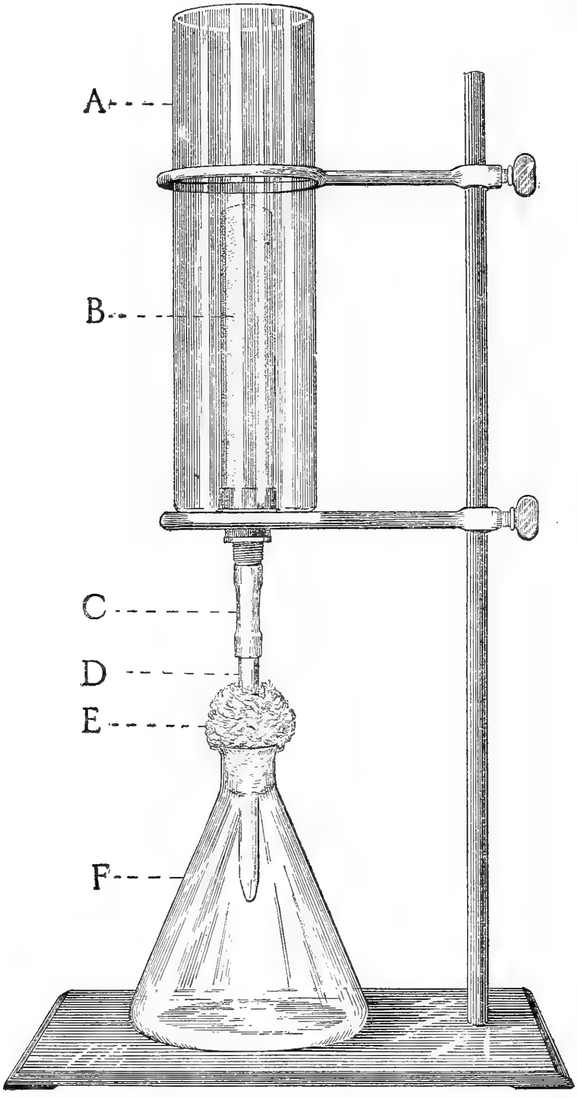


FIG. 26.—Berkefeld filter (B) with the glass mantle (A), glass tubing (D), a connecting rubber tubing (C), and a flask (F) with a cotton plug (E). (Original.)

certain extent, at least, passes through the Berkefeld filter. With this filter the virus is therefore filterable.

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[1] In referring to the infecting agent in sacbrood, the term "virus" is preferable to the terms "germ" or "parasite." In relation to the disease, however, its meaning is the same as that conveyed by the latter terms.

In the study of the virus of sacbrood use has been made also of the Pasteur-Chamberland filter [1] (fig. 27). This is a clay filter, the pores of which are much finer than those of the Berkefeld used. In using this filter, an aqueous suspension of larvæ dead of the disease is prepared as before. This is filtered by the aid of pressure obtained

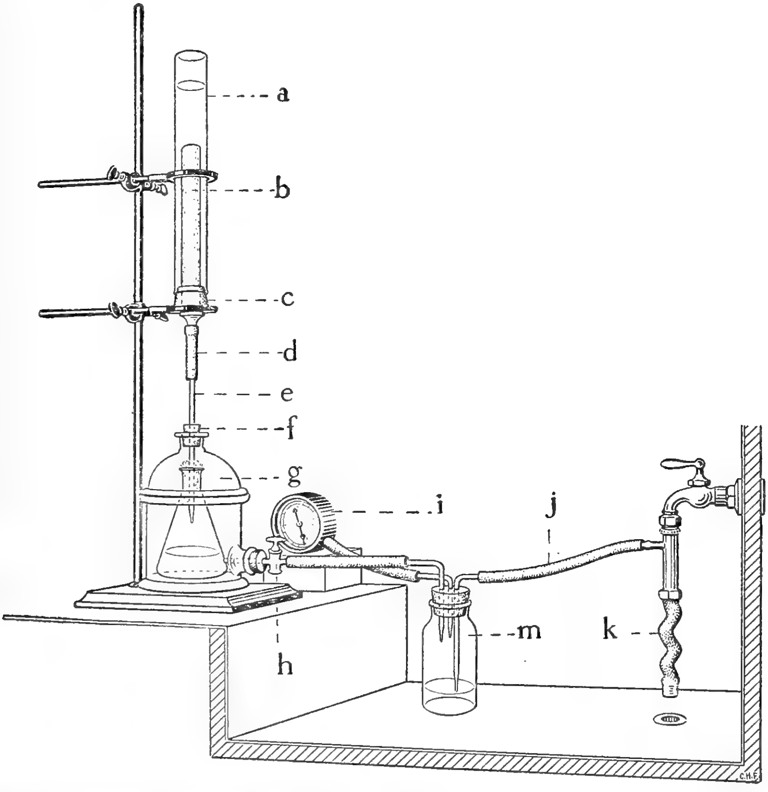

FIG. 27.—A convenient apparatus which can be employed in using the Pasteur-Chamberland, Berkefeld, and other filters. Pasteur-Chamberland filter (b) with a glass mantle (a), a rubber stopper (c) through which passes the filter, a connecting rubber tubing (d), glass tubing (e), a perforated rubber stopper (f), a vacuum jar (g), designed by the writer, in which is placed a cotton-stoppered and sterilized flask, a glass stopcock (h), a vacuum gauge (i), a reservoir (m) with pressure-rubber connections (j), and a vacuum pump (k). (Original.)

by means of a partial vacuum in an apparatus devised for this purpose. Filtrates obtained from this filter when fed to healthy colonies produced the disease. Since the virus of sacbrood will pass through

[1] The Pasteur-Chamberland filter consists of clay molded in the form of a hollow cylinder and baked. This is used with a glass cylinder (a) fitted with a rubber stopper (c). In the use of this filter, force is employed. This was obtained for these experiments through the use of a jar (g) devised by the writer in which a partial vacuum can be produced. In this jar, is placed a flask plugged with cotton and sterilized. Connections are made as shown in the illustration, the vacuum being produced through the use of the pump (k). In less than half an hour usually a half-pint of filtrate can be obtained with this apparatus.

the pores of the Pasteur-Chamberland filter also, it is therefore filterable and is very properly referred to as a "filterable"[1] virus.

In considering the virus of sacbrood it is suggested that the beekeeper think of it as a microorganism [2] which is so small or of such a nature that it has not been seen, and which will pass through the pores of fine clay filters. This conception of it will at least make it more easily understood.

WEAKENING EFFECT OF SACBROOD UPON A COLONY.

The first inoculations in proving that sacbrood is an infectious disease were made on June 25, 1912. Two colonies were used, each being fed with material from a different source. The inoculation feedings were made on successive days. Sacbrood having been produced in the colonies, the inoculations were continued at intervals throughout July and August. During this period, a large amount of sacbrood was present in both colonies. By the end of July these colonies had become noticeably weakened, and by the end of August they had become very much weakened, as a result of the sacbrood present in them. On September 5 one of the colonies swarmed out.

The brood (Pl. IV) of this colony, large in quantity, was practically all dying of sacbrood. The other colony, when examined on September 16, was found to be very weak. At this time, however, most of the dead brood had been removed and healthy brood was being reared. This colony increased in strength and wintered successfully.

The results obtained from the inoculation of these two colonies demonstrated not only that sacbrood is an infectious disease, but also that the disease in a colony tends to weaken it. The results indicate also that a colony may be destroyed by the disease, or it may recover from it, gain in strength, and winter successfully.

Each year since 1912 two or more colonies have been fed sacbrood material at intervals during the brood-rearing season for the purpose of obtaining disease material for experimental purposes. The inoculated colonies in all instances have shown a tendency to become weakened as a result of the inoculations.

The death of the worker larvæ is the primary cause for the weakness resulting from the disease in a colony. Another point to be thought of is that dead sacbrood larvæ remaining in the cells for weeks, as they not infrequently do, reduce the capacity of the brood nest for brood rearing, which has a tendency also to weaken the colony.

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[1] In searching the tissues of larvæ dead of sacbrood and the filtrates obtained from them nothing has been discovered by the aid of the microscope, or culturally, which has yet been demonstrated as being the infecting agent. This being true, the virus could be spoken of tentatively as an "ultramicroscopic virus." It is preferable, for the present, however, to refer to it simply as a filterable virus.

[2] There is some question whether, in the case of diseases having a virus which is filterable, the infecting agent is in every instance a microorganism. The evidence is strong, however, that it is.

AMOUNT OF VIRUS REQUIRED TO PRODUCE THE DISEASE, AND THE RAPIDITY OF ITS INCREASE.

Assuming the virus of sacbrood to be a very minute microorganism, the number of germs present in a larva dying of the disease must be considered as exceedingly large. Whether a single germ taken up by a larva will produce the disease in every instance, or in any instance, is not known. If the disease does result at any time from the ingestion of a single germ, all of the conditions, it may be assumed, must be especially favorable for the production of the disease. From what is known of diseases of other animals and of man, and from the results thus far obtained in the study of sacbrood, it is well, at present, to assume that the number of sacbrood germs taken up by a larva may be so small that no disease results.

It is certain, however, that a comparatively small number of sacbrood germs ingested by a larva about two days old are sufficient to produce the disease. That the few germs thus taken up can increase within the larva during an incubation period of five or six days to such a vast number as is assumed to be present in a larva dying of the disease indicates the extreme rapidity with which the germs are able to multiply.

The minimum quantity of virus necessary to produce a moderate infection in a colony has not been definitely determined. It was found by experiments, however, that the virus contained in a single larva recently dead of the disease was sufficient to produce a large amount of sacbrood in a colony.

As a very rough estimate, it may be said that the quantity of virus in a single larva dead of sacbrood is sufficient, when suspended in half a pint of sirup and fed to a healthy colony, to produce infection in and death of at least 3,000 larvæ. Starting then with the virus contained in a single larva, in less than one week it would easily be possible to have 3,000 larvæ dead of the disease, which means that the virus has been increased 3,000-fold within one week. This latter amount of virus would be sufficient to produce an equal amount of infection in 3,000 colonies, increasing the amount of virus again 3,000-fold. In less than two weeks, therefore, theoretically it would be possible to produce a sufficient amount of virus to infect 9,000,000 colonies, more colonies probably than are to be found at present in the United States. Carrying the idea somewhat further, within three weeks, theoretically enough virus could be produced to inoculate every colony in existence.

These facts are sufficient to indicate somewhat the enormous rapidity with which the virus of sacbrood is capable of increasing.

METHODS USED IN MAKING EXPERIMENTAL INOCULATIONS.

The laboratory study of bee diseases being new, it has been necessary in many instances to devise new methods. In the experimental inoculations of bees the methods used have undergone revision from time to time. Those now employed have proved quite satisfactory.

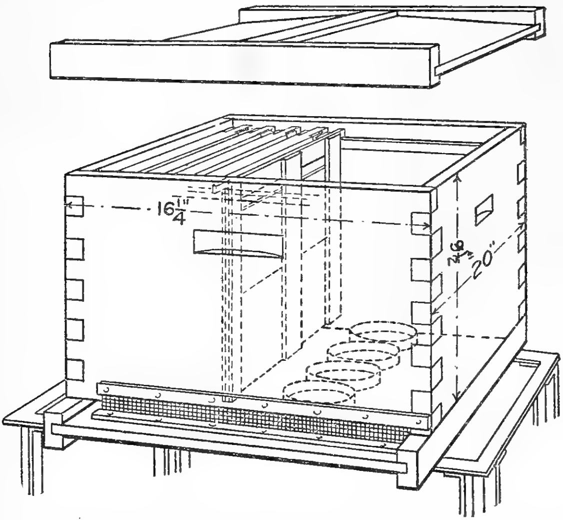


FIG. 28.—The hive as it is employed to house and feed a colony used for experimental inoculations. Here are shown four Hoffman frames, a division board, four open Petri dishes as feeders, and the entrance nearly closed with wire cloth, the opening being on the side of the hive body occupied by the colony. The dimensions indicated are approximate. The angle at which the hive was photographed for this drawing caused its length to appear foreshortened. (Original.)

As the virus of sacbrood has not been cultivated in the laboratory artificially, it has been necessary in these investigations to inoculate a large number of colonies. A nucleus of bees that could be accommodated on from 3 to 6 brood frames was found to serve very satisfactorily the purpose of an experimental colony. The queen should always be clipped. The frames are placed in one side of a 10-frame hive body (fig. 28). Over the entrance to the hive is placed wire cloth, leaving a small space of about 1 inch in length on the side occupied by the brood frames. Petri dishes [1] (fig. 29) serve well the purpose of a feeder. Both halves of the dish are used as receptacles. These are placed, preferably about four of the halves, within the hive on the bottom board on the side not occupied by frames. The hives of the experimental apiary (Pl. III) are arranged chiefly in pairs, with the entrances of consecutive rows pointing in opposite directions. The space occupied by the apiary should be

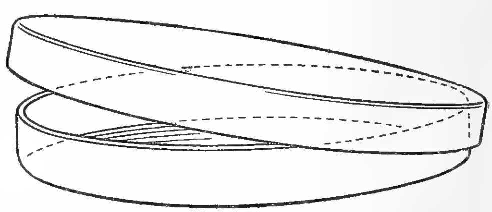
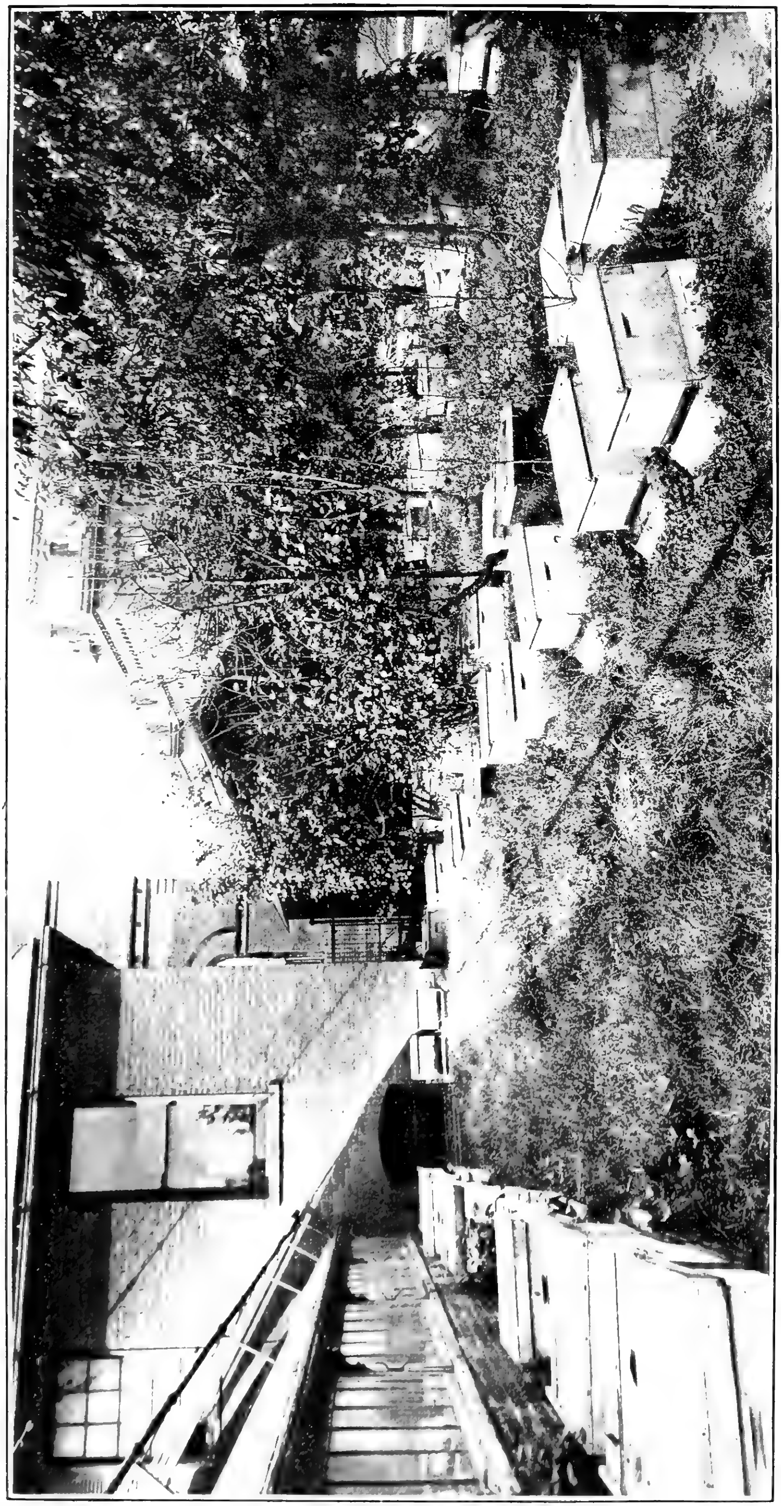
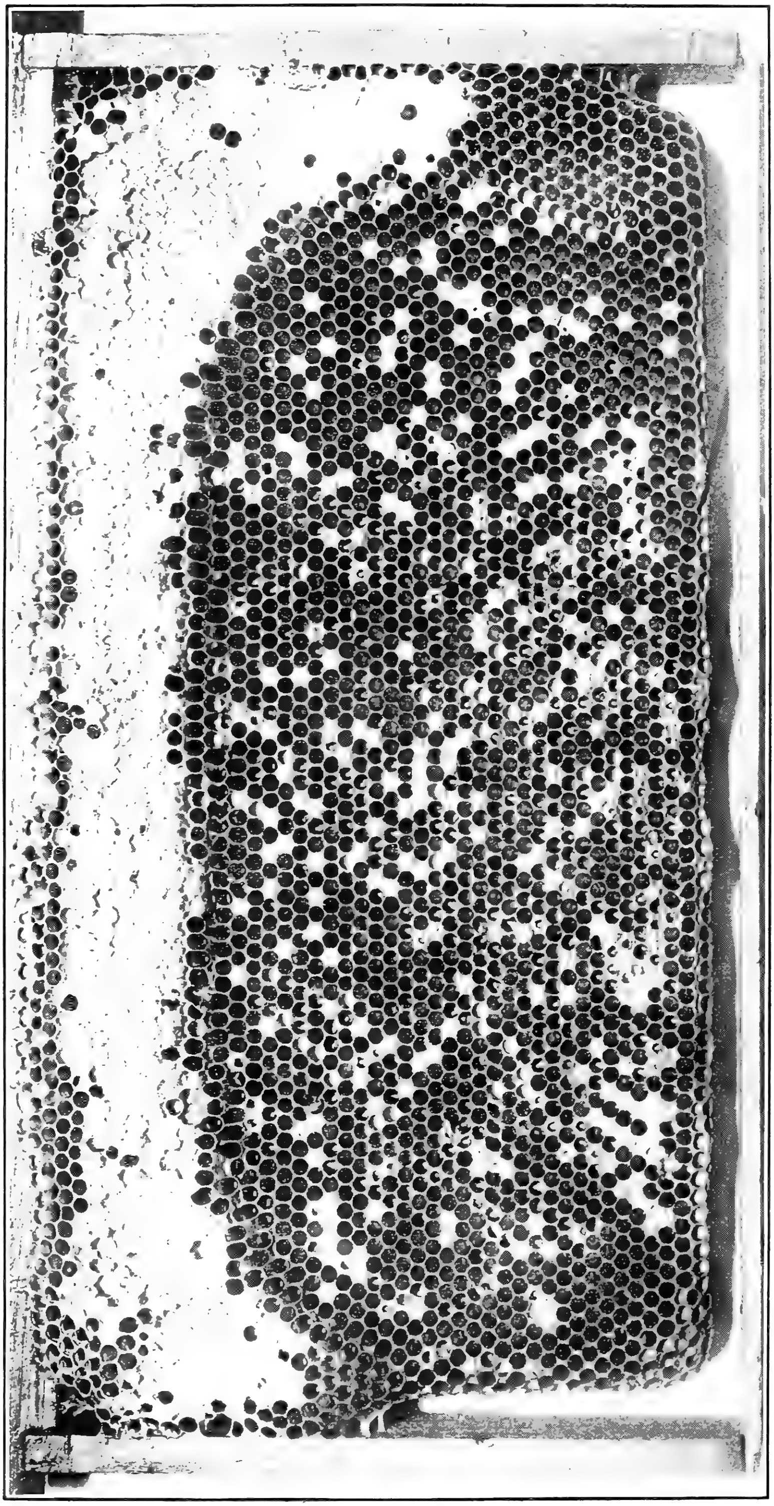


FIG. 29.—Petri dish. The top half is slightly raised. Those used here are 4 inches in diameter. (Original.)

[1] A Petri dish, a much-used piece of apparatus in a laboratory, is simply a shallow, circular, glass dish with a flat bottom and perpendicular sides. It consists of two halves, a bottom and a top. These are very similar. The top half, being slightly larger, fits over the bottom one when the two halves are placed together.



A VIEW OF THE EXPERIMENTAL APIARY OF 54 COLONIES IN WHICH THE INOCULATION EXPERIMENTS MADE DURING THE SUMMER OF 1915 WERE CONDUCTED. (ORIGINAL.)



BROOD FRAME CONTAINING SACBROOD, TAKEN FROM AN EXPERIMENTAL COLONY IN WHICH THE DISEASE WAS PRODUCED BY FEEDING THE VIRUS OF THE DISEASE. (ORIGINAL.)

broken up, preferably by trees or shrubbery. By these means, it will be observed, there is a tendency to minimize the likelihood of robbing, swarming, absconding, and accidental straying or drifting of bees to foreign colonies.

In preparing the material with which the colony is inoculated, larvæ in early stages of the disease are picked from the brood frames, crushed, and added to sugar sirup. The crushed mass from 10 or more sacbrood larvæ, suspended in somewhat more than half a pint of sugar sirup, has been found to be a suitable quantity of the infective material to use in making an inoculation. The suspension may be fed to the bees as one feeding or more. The inoculation feedings should be made as a rule toward evening to avoid the tendency to rob, which may be noticed during a dearth of nectar. Inoculations should not be made when the tendency to rob is at all marked.

Before a colony is inoculated it should be determined that its activities are normal. A colony should not be inoculated for several days after it has been made by division, or immediately after its removal from a foreign location. An experimental colony when inoculated should have larvæ of all ages, and a queen doing well.

Between five and six days after a colony has been inoculated with sacbrood virus, the first symptoms of the disease are to be expected. The finding of capped larvæ having a slightly yellowish hue (fig. 12; Pl. II, *b*, *h*) is the best early symptom by which the presence of the disease may be known.

FIG. 30.—Capillary pipette. A piece of glass tubing drawn to capillary size at one end. Reduced to three-fourths of the size used. (Original.)

Another method of inoculation may be used and under certain circumstances is desirable. The method is more direct than the one just described. The crushed tissues of a diseased larva are suspended in a small amount of water or thin sugar sirup. With a capillary pipette (fig. 30) made from small glass tubing, a very small amount of the suspension is added directly to the food which surrounds the healthy larva in the cell. This is easily done. Having drawn some of the suspension into the pipette, carefully touch the food in the cell surrounding the larva with the point of the pipette. A small amount of the suspension will flow out and mix with the food. Larvæ approximately two days of age should be selected for feeding. A dozen or more should be fed in making an inoculation. The area of brood inoculated may be designated by marking on the brood frame, or by removing the brood from around the area inoculated, thus marking it off.

MEANS FOR THE DESTRUCTION OF THE VIRUS OF SACBROOD.

Although the virus of sacbrood may increase with great rapidity, fortunately it is quite as readily destroyed. Nature supplies many means by which this may be accomplished. While theoretically a sufficient amount of virus may be produced within one month to inoculate all the bees in existence, within another month, if left to natural means alone, practically all such virus would be destroyed. This latter fact constitutes one of the chief reasons for the comparatively rapid self-recovery of colonies from this disease.

It was observed in the experiments that larvæ dead of sacbrood when left in the brood comb ceased to be infectious in less than one month after death.

HEATING REQUIRED TO DESTROY SACBROOD VIRUS WHEN SUSPENDED IN WATER.

Approximate results have been published (White, 1914) relative to the heating that is necessary to destroy the virus of sacbrood when it is suspended in water. In the following table are given some results which have been obtained:

TABLE I.—*Effect of heating on the virus of sacbrood suspended in water.*[1]

Date of inoculation.	Temperature.		Time of heating.	Results of inoculation.
	°F.	*°C.*	*Minutes.*	
Aug. 6, 1913	122	50	30	Sacbrood produced.
Sept. 10, 1913	131	55	10	Do.
Sept. 9, 1913	131	55	20	Do.
Sept. 18, 1913	135	57	15	Do.
June 30, 1915	136	58	10	Do.
Sept. 10, 1913	136	58	10	No disease produced.
Aug. 28, 1915	138	59	10	Do.
Sept. 10, 1913	140	60	15	Do.
Aug. 28, 1915	142	61	10	Do.
Aug. 26, 1913	149	65	15	Do.
Do	158	70	15	Do.
Do	167	75	15	Do.
Do	176	80	15	Do.

[1] Fractions will be omitted in this paper, the nearest whole number being given.

It will be observed from Table I that 138° F. (59° C.) maintained for 10 minutes was sufficient to destroy the virus of sacbrood in the inoculation experiments recorded. Technically, in view of the variable factors which must be considered in experiments of this kind, this result, as representing the thermal death point of the sacbrood virus, should be considered as being only approximate. For practical purposes, however, it is sufficient.

In performing these experiments a crushed mass, representing from 10 to 20 larvæ recently dead of the disease, is diluted to about 10 times its volume with tap water. About one-half ounce of this suspension is placed in a test tube (fig. 31), almost filling it. The tube is stoppered with a perforated cork, bearing a short glass tube of small caliber and drawn at one end to capillary size. This is all immersed in water at a temperature to which it is desired that the virus shall be heated. It requires nearly five minutes for the temperature of the suspension in the tube to reach that of the water outside. After reaching the degree desired the temperature is maintained for 10 minutes, after which the tube is removed and the contents added to about one-half pint of sirup. The suspension is then fed to a healthy colony. If by such a feeding no sacbrood is produced, the virus is considered as having been destroyed by the heating. On the other hand, if the disease is produced it follows naturally that the virus had not been destroyed.

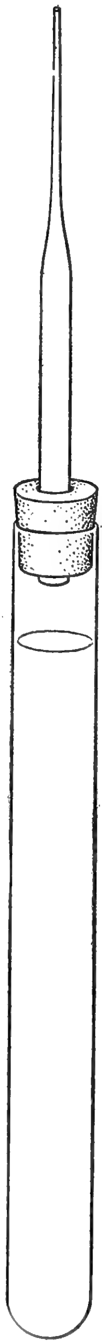


FIG. 31.—Tube in which a suspension of sacbrood larvæ is placed for heating. It consists of a test tube one-half inch in diameter supplied with a perforated stopper through which passes a short piece of glass tubing drawn at one end to capillary size. (Original.)

HEATING REQUIRED TO DESTROY SACBROOD VIRUS WHEN SUSPENDED IN GLYCERINE.

In determining the amount of heating that is necessary to destroy the virus of a disease when it is suspended in a liquid, the results should always be given in terms of at least the three factors, (1) degree of temperature, (2) time of heating, and (3) the medium in which the virus is suspended.

With the virus of sacbrood the results vary markedly, depending upon the nature of the liquid in which the suspension is made. To illustrate this point the results of a few inoculation experiments are given here in which the virus was heated while suspended in glycerine.

TABLE II.—*Effect produced by heating the virus of sacbrood suspended in glycerine.*

Date of inoculation.	Temperature.		Time of heating.	Results of inoculation.
	°F.	°C.	*Minutes.*	
June 25, 1915	140	60	10	Sacbrood produced.
June 24, 1915	149	65	10	Do.
June 25, 1915	158	70	10	Do.
Aug. 28, 1915	160	71	10	Do.
Do	163	73	10	No disease produced.
Aug. 7, 1915	167	75	10	Do.

In these inoculations it will be observed that a temperature somewhat greater than 158° F. (70° C.) maintained for 10 minutes was necessary to destroy the virus of sacbrood when it was suspended in glycerine, while a temperature somewhat less than 140° F. (60° C.) is sufficient to destroy it when suspended in water (p. 34). The same technique was employed when glycerine was used as the suspending medium as was employed when water was used as the medium. The same strain of virus was used in both instances. The point here illustrated is of special interest in connection with the heating of honey containing the virus of sacbrood.

HEATING REQUIRED TO DESTROY SACBROOD VIRUS WHEN SUSPENDED IN HONEY.

From the results obtained by heating the virus of sacbrood in glycerine as given above it might be expected that a higher temperature would be necessary to destroy the virus when it is suspended in honey than when it is suspended in water.

In determining the heating necessary to destroy the virus when suspended in honey the technique followed was similar to that employed when water and glycerine suspensions were used. The virus used in the inoculations bearing the date 1915 was of the same strain in all instances.

TABLE III.—*Results obtained when the virus of sacbrood was heated in honey.*

Date of inoculation.	Temperature.		Time of heating.	Results of inoculation.
	° F.	*° C.*	*Minutes.*	
June 1, 1915	140	60	10	Sacbrood produced.
June 11, 1915	145	63	10	Do.
Do	149	65	10	Do.
June 4, 1915	154	68	10	Do.
June 24, 1915	156	69	10	Do.
Do	158	70	10	Do.
June 1, 1915	158	70	10	No disease produced.
June 18, 1915	158	70	10	Do.
July 3, 1915	160	71	10	Do.
Aug. 28, 1915	160	71	10	Do.
Aug. 7, 1915	163	73	10	Do.
Aug. 28, 1915	163	73	10	Do.
June 1, 1915	167	75	10	Do.
Aug. 7, 1915	167	75	10	Do.
June 1, 1915	176	80	10	Do.

As shown by the results recorded in Table III, the virus of sacbrood when suspended in honey was destroyed in 10 minutes at a temperature very near 158° F. (70° C.). This temperature is more than 18° F. (10° C.) greater than the temperature required to destroy in the same time the virus when suspended in water and approximately equal to that necessary to destroy it when suspended in glycerine.

RESISTANCE OF SACBROOD VIRUS TO DRYING AT ROOM TEMPERATURE.

In the experiments made for the purpose of determining the amount of drying which the virus of sacbrood will withstand, larvæ recently dead of the disease were used. These are crushed, strained through cheesecloth, and the crushed mass poured into Petri dishes (fig. 32) to the extent of a thin layer for each dish, the material in each being the crushed remains of about 30 larvæ. These are placed in a drawer, shielding the larval material from the light. The drying then proceeds at the temperature of the room. This temperature varied greatly from day to day, sometimes being as high as 93° F. (34° C.).

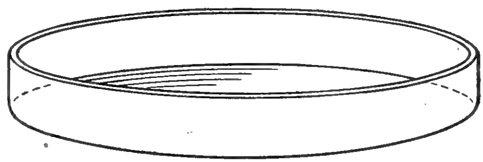


Fig. 32.—Open Petri dish. One-half of Petri dish, either top or bottom. (Original.)

At intervals, reckoned in days, after the preparation of the virus, colonies are inoculated. An aqueous suspension is made of the drying larval content contained in a Petri dish. This is added to sirup, and the sirup suspension is fed to a healthy colony. The experiments gave the following results:

Table IV.—*Resistance of sacbrood virus to drying at room temperature.*

Date of inoculation.	Time of drying.	Results of inoculation.
Aug. 8, 1914	3 days	Sacbrood produced.
Aug. 14, 1914	7 days	Do.
Sept. 6, 1915	13 days	Do.
July 1, 1915	16 days	Do.
Sept. 28, 1915	18 days	Do.
July 6, 1915	20 days	Do.
Sept. 3, 1915	22 days	No sacbrood produced.
Sept. 27, 1915	26 days	Do.
Oct. 9, 1914	28 days	No.
July 29, 1915	28 days	Do.
Sept. 3, 1915	35 days	Do.
Do	45 days	Do.
May 22, 1915	7 months 12 days	Do.
Do	7 months 21 days	Do.

From the results recorded in Table IV it will be noted that the virus of sacbrood in the experiment referred to withstood drying at room temperature for approximately three weeks.

The inoculations made during the third week indicated, by the reduced amount of sacbrood produced, that much of the virus had already been destroyed. Obtaining negative results from the use of larval material which had been drying more than seven months tends toward eliminating the possibility that the virus possesses a resting stage.

Similar preliminary experiments made to determine the amount of drying which the virus of sacbrood will withstand at outdoor temperature and at incubator temperature (about 99° F. [37° C.]) gave results approximately those obtained from drying at room temperature, the time being somewhat less in the case of drying at incubator temperature.

Preliminary experiments indicate also that when the virus is mixed with pollen and allowed to dry the period for which it remains virulent is increased only slightly.

RESISTANCE OF SACBROOD VIRUS TO DIRECT SUNLIGHT WHEN DRY.

In the experiments made to determine the amount of sunlight which the virus of sacbrood is capable of resisting, Petri-dish preparations similar to those made in the drying experiment were prepared. After drying a few hours in the room the uncovered dish is exposed to the direct rays of the sun. At different intervals, measured in hours, inoculations of healthy colonies are made similar to those in the drying experiments. The following results were obtained:

Table V.—*Resistance of the virus of sacbrood, when dry, to direct sunlight.*

Date of inoculation.	Time of exposure to sun's rays.	Results of inoculation.
	Hours.	
Sept. 17, 1915	2	Sacbrood produced.
July 29, 1915	2½	Do.
Sept. 17, 1915	3	Do.
Sept. 16, 1915	4	Do.
Do	5	Do.
Do	6	Do.
Aug. 25, 1915	6	Do.
Sept. 10, 1915	4	No disease produced.
Do	5	Do.
Sept. 9, 1915	7	Do.
Do	9	Do.
Aug. 19, 1915	12	Do.
July 16, 1915	13	Do.
Aug. 20, 1915	18	Do.
Sept. 11, 1915	21	Do.

The results recorded in Table V show that the virus of sacbrood in the experiments made was destroyed in from four to seven hours' exposure to the direct rays of the sun. The results obtained also indicate that much of the virus was destroyed in a 2-hour exposure to the sun.

It will be readily appreciated that the time that the virus will resist the sun's rays will depend a great deal upon the intensity of the rays at the time of its exposure and the thickness of the layer of the infective larval material in the Petri dish. The drying that would naturally take place during the exposure to the sun would tend also to destroy the virus, but as the resistance to drying is better given in weeks than days, this factor may be disregarded here.

RESISTANCE OF SACBROOD VIRUS TO DIRECT SUNLIGHT WHEN SUSPENDED IN WATER.

In the experiments made for the purpose of determining the resistance of the virus of sacbrood to the direct rays of the sun when suspended in water, Petri dishes were again used. About 1½ ounces of the aqueous suspension containing the crushed tissues of 30 larvæ is poured into the dish and exposed to the direct rays of the sun. After intervals reckoned in hours the inoculations of healthy colonies are made. The contents of a single Petri dish are added to about one-half pint of sirup and the suspension fed to a healthy colony. The following results were obtained from the experiments:

TABLE VI.—*Resistance of sacbrood virus to the direct rays of the sun when suspended in water.*

Date of inoculation.	Time of exposure to sun's rays.	Results of inoculation.
	Hours.	
Sept. 10, 1915	1	Sacbrood produced.
Aug. 20, 1915	2	Do.
Sept. 14, 1915	2	Do.
Aug. 24, 1915	2	Do.
Aug. 18, 1915	3	Do.
Sept. 9, 1915	4	Do.
Sept. 10, 1915	4	Do.
Aug. 24, 1915	5	Do.
Do	4	No disease produced.
Aug. 16, 1915	5	Do.
Sept. 8, 1915	5	Do.
Do	6	Do.
Sept. 9, 1915	7	Do.
Do	8	Do.
Aug. 25, 1915	10	Do.
Aug. 20, 1915	12	Do.
July 13, 1915	13	Do.
Aug. 26, 1915	13	Do.

From Table VI it will be seen that when suspended in water the virus of sacbrood was killed in from four to six hours.

The aqueous suspensions in the Petri dishes in these experiments did not reach by several degrees the temperature 138° F. (59° C.) at which the virus is destroyed readily by heating (p. 34). Naturally experiments of the nature of those in this group will vary in all cases with the intensity of the sun's rays to which the virus is exposed. The exposures were made in these experiments between 9 and 4 o'clock, the sun's rays toward the middle of the day being most often used.

RESISTANCE OF SACBROOD VIRUS TO DIRECT SUNLIGHT WHEN SUSPENDED IN HONEY.

The crushed and strained tissue mass of larvæ dead of sacbrood was suspended in honey and exposed to the direct rays of the sun. To prevent robbing by bees, closed Petri dishes were used. At intervals reckoned in hours healthy colonies were inoculated, each with the virus from a single Petri dish. The exposures were made during the day between 9 and 4 o'clock, preference being given to the hours near midday. The group of experiments conducted on this point gave the following results:

TABLE VII.—*Resistance of the sacbrood virus to direct sunlight when suspended in honey.*

Date of inoculation.	Time of exposure to sun's rays.	Results of inoculation.
	Hours.	
Aug. 24, 1915	1	Sacbrood produced.
Do	2	Do.
Aug. 18, 1915	4	Do.
Sept. 9, 1915	4	Do.
Sept. 10, 1915	4	Do.
Aug. 24, 1915	5	Do.
Aug. 16, 1915	5	No disease produced.
Aug. 25, 1915	5	Do.
Sept. 8, 1915	5	Do.
Do	6	Do.
Sept. 9, 1915	7	Do.
Do	8	Do.
Aug. 25, 1915	10	Do.
Sept. 11, 1915	12	Do.
Aug. 26, 1915	13	Do.
Sept. 11, 1915	18	Do.

From the results of the experiments recorded in Table VII it will be observed that the virus of sacbrood when suspended in honey was destroyed by the direct rays of the sun in from five to six hours. These figures represent the time for destruction of all of the virus used in each experiment. The results obtained from the experiments indicate, however, that much of it was destroyed earlier.

LENGTH OF TIME THAT SACBROOD VIRUS REMAINS VIRULENT IN HONEY.

In devising methods for the treatment of sacbrood it is of particular interest to know the length of time that the virus will remain virulent when it is in honey. Experiments have been made to gain data on this point. Larvæ recently dead of sacbrood are crushed, strained, and suspended in honey. About one-half pint of the suspension, representing the virus from about 30 dead larvæ, is placed in each of a number of glass flasks. These are allowed to stand at room temperature, being shielded from the light by being placed in a closed cabinet.

After periods reckoned in days inoculations of healthy colonies are made. The following results have been obtained:

TABLE VIII.—*Length of time the virus of sacbrood remains virulent in honey.*

Date of inoculation.	Time virus was in honey. Mos.	Days.	Results of inoculation.
June 17, 1915	0	20	Sacbrood produced.
June 4, 1915	0	23	Do.
Oct. 2, 1915	0	30	Do.
Sept. 3, 1915	0	24	No disease produced.
July 29, 1915	0	29	Do.
June 30, 1915	0	33	Do.
Do.	0	35	Do.
July 17, 1915	0	36	Do.
Oct. 21, 1915	0	49	Do.
Sept. 8, 1915	0	70	Do.
May 13, 1915	[1] 7	10	Do.
May 6, 1915	7	20	Do.
May 4, 1915	8	2	Do.
May 18, 1915	8	21	Do.
Sept. 3, 1915	12	1	Do.

[1] The dead brown larval remains were not crushed before being introduced into the honey.

The experiments recorded in Table VIII show that the virus of sacbrood when suspended in honey at room temperature remained virulent for three weeks, but was entirely destroyed before the end of the fifth week. It is most likely that the virus in most instances is destroyed by the end of one month at this temperature.

The experiments in which the virus had been allowed to remain in the honey for more than seven months suggest that there is probably no resting stage of the virus to be considered in this connection. The facts tend to indicate that the virus does not receive any marked amount of protection by being in honey. From the dates of the experiments in this group it will be noted that the virus was subjected to summer temperature. The evidence at hand indicates that it remains virulent somewhat longer when the temperature is lower.

RESISTANCE OF SACBROOD VIRUS TO THE PRESENCE OF FERMENTATIVE PROCESSES.

Fermentation and putrefaction [1] are other means by which the virus of sacbrood may be destroyed in water. A crushed and strained mass of tissue from larvæ recently dead of the disease is suspended in a 10 per cent sugar (granulated or cane sugar) solution.

[1] "Fermentation" has reference here particularly to the breaking up of carbohydrate substances by the growth of microorganisms, the sugars in honey being naturally the carbohydrates especially of interest in these discussions. The process results in the formation of a large number of substances—acids, alcohols, etc. The odor accompanying such a process could not be called offensive. By the term "putrefaction" is meant the breaking up of nitrogenous organic substances by microorganisms. These have a chemical composition quite different from the carbohydrates. When broken up the resulting substances are more often alkaline in nature. The odor from a suspension in which putrefactive processes are going on is usually distinctly offensive.

A small quantity of soil is added to inoculate the suspension further. This is then distributed in test tubes (fig. 33), the quantity in each tube representing the virus from about 15 larvæ. These suspensions are allowed to remain at room temperature, shielded from the light. Under these conditions fermentation goes on rather rapidly.

After intervals reckoned in days colonies free from the disease are inoculated, each with the suspension from a single tube. Results from such inoculations are given in the following table:

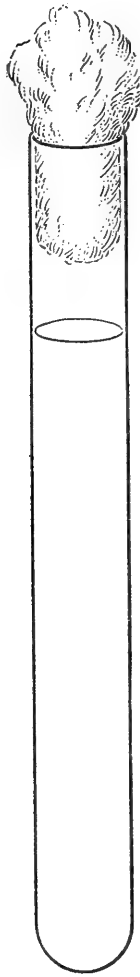


FIG. 33.—Test tube bearing a cotton plug, used in testing the effect of fermentation, putrefaction, and disinfecting agents on the virus of sacbrood. (Original.)

TABLE IX.—*Resistance of sacbrood virus to fermentation in a 10 per cent sugar solution at room temperature.*

Date of inoculation.	Period of fermentation.	Results of inoculation.
	Days.	
Sept. 9, 1915	1	Sacbrood produced.
Sept. 11, 1915	2	Do.
Do	3	Do.
Sept. 13, 1915	4	Do.
July 14, 1915	3	No disease produced.
July 22, 1915	5	Do.
Sept. 14, 1915	5	Do.
Sept. 22, 1915	7	Do.
July 10, 1915	9	Do.
June 10, 1915	13	Do.
July 7, 1914 [1]	34	Do.
Aug. 27, 1914	51	Do.
Do	85	Do.
Do	87	Do.
Do	90	Do.
Do	244	Do.

[1] The results recorded for 1914 were obtained with a suspension of crushed larvæ, in various stages of decay, in sirup made from about equal parts water and sugar.

From the results of experiments recorded in Table IX it will be noted that the virus of sacbrood was destroyed in from three to five days in the presence of fermentation in 10 per cent cane sugar (saccharose) at room temperature.

As the rapidity of fermentative processes varies with the temperature present, it is natural to suppose that the time required for the destruction of the virus will vary. From experiments it is found that at incubator temperature the time is slightly less, and at outdoor temperature it is somewhat greater than at room temperature.

RESISTANCE OF SACBROOD VIRUS TO FERMENTATION IN DILUTED HONEY AT OUTDOOR TEMPERATURE.

Employing the egg test [1] as used by beekeepers in diluting honey for the purpose of making vinegar, it is found that it requires about

[1] This test is applied in the following manner: Water is added to honey until an egg placed in the mixture is nearly submerged, the surface remaining above the liquid being only about as large as a 10-cent piece.

four volumes of water to one of ripened honey to obtain the strength recommended. The honey solution by volume, therefore, is about 20 per cent honey.

A suspension of the virus of sacbrood in such a solution is distributed in test tubes placed in an empty hive body and allowed to ferment at outdoor temperature. After periods reckoned in days colonies are inoculated as was done in case of the sugar solutions described above. The following results were obtained from the experiments performed:

TABLE X.—*Resistance of sacbrood virus to fermentative processes in a 20 per cent honey solution at outdoor temperature.*

Date of inoculation.	Time of fermentation.	Results of inoculation.
	Days.	
Sept. 11, 1915	3	Sacbrood produced.
Sept. 13, 1915	4	Do.
Sept. 14, 1915	5	No disease produced.
Aug. 4, 1915	6	Do.
Sept. 15, 1915	6	Do.
Sept. 14, 1915	7	Do.
Sept. 22, 1915	7	Do.
Sept. 17, 1915	8	Do.
Sept. 8, 1915	40	Do.

In the presence of fermentative processes taking place in a 20 per cent honey solution at outdoor temperature it will be observed that the virus of sacbrood in the experiments recorded in Table X was destroyed in six days. The outdoor temperature during these experiments was quite warm. Had it been cooler, the time for the destruction of the virus would have been somewhat increased. In the making of vinegar it may be concluded that the virus of sacbrood, should it be present in the honey used, would be destroyed in a comparatively short time as a result of fermentation.

RESISTANCE OF SACBROOD VIRUS TO THE PRESENCE OF PUTREFACTIVE PROCESSES.

Larvæ containing the virus of sacbrood are crushed and suspended in water. A small quantity of soil is added. The suspension is strained and distributed in test tubes. These are allowed to stand at room temperature in a state of putrefaction. After periods reckoned in days colonies free from the disease are inoculated, each with the contents of a single tube added to sirup. From experiments of this kind the results following have been obtained.

TABLE XI.—*Resistance of sacbrood virus to putrefaction.*

Date of inoculation.	Time of putrefaction.	Results of inoculation.
	Days.	
Aug. 6, 1914	1	Sacbrood produced.
Aug. 7, 1914	2	Do.
Aug. 10, 1914	3	Do.
July 20, 1915	3	Do.
Sept. 13, 1915	4	Do.
Sept. 14, 1915	5	Do.
July 22, 1915	5	Do.
July 8, 1915	7	Do.
May 22, 1915	9	Do.
Sept. 22, 1915	7	No disease produced.
Aug. 18, 1915	10	Do.
Sept. 16, 1914	14	Do.
Sept. 25, 1914	14	Do.
July 1, 1915	16	Do.

From Table XI it will be noted that the virus of sacbrood was destroyed in the experiments recorded in from 7 to 10 days. As in the case of fermentation, so in the case of putrefaction, it is to be expected that the time for the destruction of the virus will vary appreciably with the temperature at which the putrefactive processes take place.

RESISTANCE OF SACBROOD VIRUS TO CARBOLIC ACID.

Larvæ recently dead of sacbrood are crushed and strained. This larval mass is diluted with carbolic acid in aqueous solution. About 10 parts of carbolic acid to 1 part of the larval mass is used. This suspension is distributed in test tubes and allowed to stand at room temperature. Each tube contains the virus from about 15 larvæ. After periods, reckoned in days, colonies free from disease are inoculated, each with the contents of a single tube added to sirup.

Carbolic acid solutions of ½, 1, 2, and 4 per cent were used in making the suspensions. The following results were obtained from the experiments:

TABLE XII.—*Resistance of sacbrood virus to carbolic acid.*

Date of inoculation.	Strength of carbolic acid used.	Time in suspension.	Results of inoculation.
	Per cent.	*Days.*	
Sept. 3, 1914	½	1	Sacbrood produced.
Sept. 18, 1914	½	16	Do.
Sept. 3, 1914	½	24	Do.
Sept. 17, 1914	½	38	No disease produced.
Aug. 12, 1915	½	50	Do.
Aug. 20, 1915	½	50	Do.
May 14, 1915	½	238	Do.
Sept. 3, 1914	1	1	Sacbrood produced.
Sept. 18, 1914	1	16	Do.
June 23, 1915	1	25	Do.
Sept. 17, 1915	1	38	No disease produced.
Aug. 12, 1915	1	50	Do.
Aug. 21, 1915	1	50	Do.
June 4, 1915	1	251	Do.

TABLE XII.—*Resistance of sacbrood virus to carbolic acid*—Continued.

Date of inoculation.	Strength of carbolic acid used.	Time in suspension.	Results of inoculation.
	Per cent.	*Days.*	
Sept. 3, 1914	2	1	Sacbrood produced.
Sept. 18, 1914	2	16	Do.
June 23, 1915	2	25	Do.
Sept. 17, 1915	2	38	No disease produced.
Aug. 12, 1915	2	42	Do.
Aug. 21, 1915	2	50	Do.
		Hours.	
June 23, 1915	4	3	Sacbrood produced.
July 1, 1915	4	7	Do.
		Days.	
June 23, 1915	4	25	No disease produced.
Aug. 12, 1915	4	50	Do.

From the preliminary results recorded in Table XII it will be observed that the virus of sacbrood shows a marked resistance to the disinfecting power of carbolic acid. Under the conditions of the experiments the virus resisted its action for more than three weeks in $\frac{1}{2}$, 1, and 2 per cent aqueous solutions.

These results lead naturally to a consideration of the effect of drugs on the virus of sacbrood in the treatment of the disease. On this point complete data are yet wanting.

While the disinfecting power of a compound, as shown in experiments such as those described above for carbolic acid, may indicate something as to the value of the compound as a drug, it does not necessarily prove its value. More definite proof is gained through feeding colonies with the virus suspended in honey medicated with the drug, and then continuing to feed the inoculated colonies with honey similarly medicated daily thereafter until the time for the appearance of the disease.

To illustrate the nature of experiments which are being conducted to determine the value of drugs in the treatment of sacbrood, experiments with quinine and carbolic acid are here referred to. A colony was fed the virus of sacbrood suspended in honey and water, equal parts, to which was added 5 grains of the bisulphate of quinine to one-half pint of diluted honey, and on each of the five days following the inoculation the same colony was fed diluted honey containing no virus, but medicated with quinine in the same way. On the seventh day following the inoculation with the virus there was found to be a large quantity of sacbrood produced in the colony so inoculated and treated.

A similar experiment in which carbolized honey was used gave like results. These experiments, although not furnishing conclusive proof, do indicate something of what might be expected from the use of quinine or carbolic acid as a drug in the treatment of sacbrood.

Technically the foregoing studies should be thought of as being preliminary. Questions relating to virulence of the virus, resistance of the bees, technique, and many other factors contribute to make results such as these vary. For practical purposes, however, they are sufficiently complete. In estimating the time necessary for the destruction of the virus in practical apiculture by any of the foregoing tables of results it should be emphasized that the time element should be somewhat increased, inasmuch as the conditions present in the experiments were more favorable for its destruction than would ordinarily be the case in practice.

MODES OF TRANSMISSION OF SACBROOD.

The transmission of a brood disease must be thought of as taking place (1) from diseased to healthy brood within a colony and (2) from a diseased colony to a healthy one. The manner in which sacbrood is spread naturally depends directly upon the modes by which the virus of the disease is transmitted.

As is shown experimentally, the virus of sacbrood produces the disease when it is added directly to the food of young larvæ or when it is mixed with sirup and fed to a colony. From this fact it is fair to assume that sacbrood may result whenever the food or water used by the bees contains the living virus of the disease.

Bees have a tendency to remove diseased or dead larvæ from the cells. When the removal is attempted about the time of death, it is done piecemeal. Each fragment removed from such a larva, if fed to a young healthy larva within a week, would most likely produce sacbrood in the larva. Within the hive, therefore, the disease may be transmitted to healthy larvæ more or less directly in this way.

Just what becomes of these bits of tissue removed from the diseased larvæ, however, is not known. If it were the rule that the tissues of the dead larva after being removed in fragments were fed unaltered to the young healthy larvæ within two weeks after its removal, it would seem that the disease would increase rapidly in the colony as a result. Such an increase, however, is unusual, the tendency in a colony being in most cases toward a recovery from the disease.

This fact leads one to think of other possibilities regarding the destiny of the infected tissues removed as fragments from the diseased larvæ. If the infective material were fed to the older larvæ, death probably would not result. Should it be used by adult bees as food for themselves, the likelihood of the transmission of the disease under such circumstances would apparently be very materially reduced. If the infective material were stored with the honey and did not reach the brood within a month or six weeks, it is not probable that the disease would be transmitted under such circumstances (p. 41). Should the dead larvæ or any fragments of them be carried out of the hive, the virus would have to be returned to the hive, as a matter of course, before further infection of the brood could take place from such infective material.

It is left to be considered in what way the infective material if removed from the hive might be returned to the brood and infect it. Should any material containing the virus reach the water supply of the bees, or the flowers visited by the bees, it is within the range of possibility that some of the living virus might be returned to the hive and reach healthy young larvæ.

While out of the hive, however, the virus must withstand certain destructive agencies in nature. Under more or less favorable circumstances it would withstand drying alone for a few weeks (p. 37), but if exposed to the sun it might be destroyed in a few hours. (p 38). If the virus were subjected to fermentation it might be destroyed within a week (p 43), and if subjected to putrefaction, within two weeks (p. 44).

The experimental evidence indicates that the virus, once out of the hive and freed from the adult bees removing it, during the warmer seasons of the year, at least, has but little chance of being returned to the hive and producing any noticeable infection. In the experimental apiary (Pl. III) a large number of colonies have been heavily infected with sacbrood through experimental inoculation, and no infection was observed to have resulted in the uninoculated colonies. If throughout the main brood-rearing season the usual source of infection were the flowers or the water supply, a quite different result would be expected.

Tentatively it may be concluded, therefore, that the probability of the transmission of the virus of sacbrood by way of flowers visited by bees, practically considered, is quite remote, being, however, to a limited extent theoretically possible.

It would seem that there is a greater likelihood of the water supply being a source of infection than flowers. The chances for infection from this source, should it occur at all, would be greater in the spring, as at such a time the quantity of infective material in diseased colonies is greater, increasing the chances that some of it might be carried to the water supply and contaminate it, and furthermore, the destructive agencies in nature are at this time less efficient.

Bees drifting or straying from infected colonies to healthy ones must be thought of as possible transmitters of the disease. That the disease is not spread to any great extent in this way is evidenced by the fact that colonies in the apiary that were not inoculated experimentally remained free from disease, although many colonies in the apiary were heavily infected at the time.

Sacbrood has a tendency to weaken a colony in which it is present. Frequently this weakness is noticeable and often marked. Robbing, which occurs not infrequently at such a time, results in the transmission of the virus, to some extent at least, directly to healthy colonies. Robbing, therefore, must always be considered as a probable means of transmission.

The modes of transmission of sacbrood within the colony and from colony to colony, as will be seen, are not by any means completely determined. In what way the sacbrood virus is carried over from one brood-rearing season to another is one of the many problems concerning this disease that are yet to be solved. The foregoing facts, accompanied by the brief discussions, it is hoped, will throw some light upon this important phase of the study—the transmission of this disease—and will serve as an aid to later researches.

DIAGNOSIS OF SACBROOD.

The diagnosis of sacbrood can be made from the symptoms already described (p. 10). The colony may or may not be noticeably weakened. The adult bees are normal in appearance. Scattered here and there on the brood frame among the healthy brood are found dead larvæ in the late larval stage. Usually there are only a few of them, yet sometimes there are many. These larvæ may be in capped or uncapped cells. When found in uncapped cells, however, the cappings had already been removed by the bees after the death of the larvæ. The cap over a dead larva in a cell may be found punctured or not. The brood possesses no abnormal odor, or practically none.

The post-mortem appearances of larvæ dead of the disease are especially valuable in making the diagnosis. The larva is found extended lengthwise in the cell and on its dorsal side. Throughout the period of decay it will be found to maintain much of the form and markings of a healthy larva of the age at which it died. Soon after death the larval remains are slightly yellow. After a period they assume a brownish tint. Since the brown color deepens as the process of decay and drying takes place, the remains may be found having any one of a number of shades of brown. They may appear at times almost black.

After death the cuticular portion of the body wall becomes toughened, permitting the easy removal of the larva intact from the cell. When removed, the saclike appearance of the remains becomes easily apparent. Upon rupturing the cuticular sac the contents are found to be a brownish, granular-appearing mass suspended in a comparatively small quantity of more or less clear liquid. The scales formed by the drying of the decaying remains are easily removed from the cells. After becoming quite dry many of them indeed can be shaken from the brood comb.

Upon crushing larvæ which have been found dead for some time but not yet dry, a marked unpleasant odor will be noticed if the crushed mass is held near the nostrils.

Microscopically no microorganisms are to be found in the decaying remains of the larvæ. Cultures made from them are also negative.

Differential diagnosis.—Sacbrood must be differentiated from the other brood diseases.

American foulbrood may be recognized by the peculiar odor of the brood combs when the odor is present. The body wall of the larval and pupal remains is easily ruptured, and the decaying mass becomes viscid, giving the appearance popularly referred to as "ropiness." The scale adheres quite firmly to the floor of the cell. The presence of *Bacillus larvæ* in the brood dead of the disease is a positive means by which it may be differentiated from sacbrood.

European foulbrood may be recognized by the fact that the larvæ as a rule die while coiled in the cell and before an endwise position is assumed. In the majority of instances, therefore, death takes place before the cells are capped. The saclike appearance characterizing the dead larvæ in sacbrood is absent. The granular consistency of the decaying mass is absent also. Microscopically, a large number of bacteria are found in larvæ dead of European foulbrood, but are absent in larvæ dead of sacbrood. The presence of *Bacillus pluton* is a positive means by which European foulbrood may be recognized. *Bacillus alvei* and other species may also be present.

Sacbrood must also be differentiated from other conditions referred to as chilled brood, overheated brood, and starved brood, which occasionally are encountered. This can be done by a comparison of the symptoms presented by these different conditions with the symptoms of sacbrood, and the history of the cases. Some of the larvæ dead from these conditions will be found to have died while yet coiled in the cell. This fact suggests some condition other than sacbrood. When dying later, the saclike remains characterizing sacbrood are not present in conditions other than sacbrood.

PROGNOSIS.

The tendency in a colony affected with sacbrood is to recover from the disease. Colonies which during the spring months show the presence of more or less disease, by midsummer or earlier may, and very frequently do, contain no diseased brood. Experimentally it is possible to destroy a colony by feeding it repeatedly the virus of sacbrood, and beekeepers report that the disease sometimes destroys colonies in their apiaries. The percentage of colonies, however, that actually die out as a direct result of the disease is small. The weakening of the colony in the spring of the year not only reduces or entirely eliminates the profits on it for the season, but may also cause it to be in a weakened condition on the approach of winter.

Whether a larva once infected ever recovers from the disease is not known. Reasoning from what is known of the diseases of other animals and man, one would expect that a larva may recover from sacbrood infection. It is known that many larvæ, both worker and drone, do die. From the information thus far obtained it does not appear that a queenless colony would be likely to remain so as a consequence of the disease.

As to the prognosis of the disease in a colony it may be said, therefore, that it is very favorable for the continued existence of the colony. As to the economic losses to be expected from the disease, the present studies suggest that they may vary from losses that are so light as not to be detected upon examination to losses that may equal the entire profits of the colony for the year. Indeed, at times the death of the colony takes place as a result of the disease.

RELATION OF THESE STUDIES TO THE TREATMENT OF SACBROOD.

An earlier paper (White, 1908) contains a brief general discussion of the relation existing between the cause of bee diseases and the treatment of them. The general remarks made in it apply also to sacbrood. No doubt the beekeeper in studying the results given here has already observed relations existing between them and points which should be incorporated in methods for treatment. Mentioning a few of them here may serve to suggest still others.

That the weakness resulting in a sacbrood colony is due to the death of worker larvæ; that adult bees are not susceptible to the disease; that queenlessness is rarely to be expected as a sequence of the disease; that the disease may be produced with ease at any time of the year that brood is being reared; that it occurs at all seasons, but is more frequently encountered in the spring; that it is found in localities differing widely as to food and climatic conditions; and that no complete racial immunity to the disease has yet been found are facts concerning the predisposing causes of sacbrood which beekeepers will at once recognize as bearing a close relation to the methods by which the disease should be treated.

As sacbrood can not occur in the absence of its exciting cause (a filterable virus), a knowledge of this cause is of special importance in the treatment of the disease.

That sacbrood is very frequently encountered; that it is infectious, but that it is more benign in character than malignant; that it does not spread rapidly from one colony to another; that colonies manifest a strong tendency toward self-recovery from the disease; that this tendency is stronger after midsummer; that the disease may so weaken a colony during the early brood-rearing season that the profits from it may be much reduced, or even rendered nil; and that the disease may indeed destroy the colony are facts which must be considered in devising logical methods for its treatment.

That the virus of sacbrood remains virulent in larvæ dead of the disease for less than one month; that it remains virulent in honey approximately one month; that when mixed with pollen it ceases to be virulent after about one month; and that in drying no virulence is to be expected after one month, are facts that account in a large measure for the strong tendency to recover from the disease manifested by the colony and that furnish information concerning the use of combs from sacbrood colonies. From the results it may be concluded that it is better, theoretically, to store combs from sacbrood colonies for one or two months before they are again used, provided such storing entails no particular inconvenience or financial loss to the beekeeper.

Further experiments show that brood frames from badly-infected colonies may be inserted into strong, healthy ones, and cause thereby very little infection and consequently only a slight loss. This is especially true after the early brood-rearing season of the year is past. Since this can be done, it is quite probable that the practical beekeeper will find that this disposition of the combs will be the preferable one to make. At any event, it is comforting to know that it is never necessary to destroy the combs from sacbrood colonies on account of the disease.

The experimental results here given regarding the destruction of the virus through heating, fermentation, putrefaction, drying, and direct sunlight should assist materially in the solution of the problem of the transmission of sacbrood, and should be found helpful in devising efficient methods for the treatment of the disease.

Toward disinfecting agents it is shown that the virus of sacbrood possesses, in some instances at least, marked resistance. These and other experimental results thus far obtained indicate that the use of any drug in the treatment of the disease should not be depended upon until such a drug has been proved to be of value.

No fear need be entertained in practical apiculture that the disease will be transmitted by the hands or clothing of the operator, by the tools used about the apiary, through the medium of the wind, or by the queen. It would seem at all times superfluous in the case of sacbrood to flame or burn the inside of the hive or to treat the ground about a hive containing an infected colony.

There is but little danger that the disease will be transmitted by way of flowers visited by bees from sacbrood colonies and later from healthy ones.

Theoretically, it is possible that the disease may be transmitted through a contamination of the water supply by bees from sacbrood colonies. Whether infection ever takes place in this way, however, is not yet known. If the disease is ever transmitted in this way, it would seem that it is more likely to take place in the spring of the year than at any other season.

While there is yet much to be learned about sacbrood, it is hoped that by carefully considering these studies the beekeepers will be aided in devising efficient and economical methods for its treatment.

SUMMARY AND CONCLUSIONS.

The following summary and statements of conclusions seem to be justified as a result of the investigations recorded in this paper:

(1) Sacbrood is an infectious disease of the brood of bees.

(2) Adult bees are not susceptible to the disease.

(3) The infecting agent causing sacbrood is of such a nature that it passes through the pores of a fine clay filter. It is therefore a filterable virus.

(4) A colony may be inoculated by feeding it sirup or honey containing the virus.

(5) The quantity of virus contained in a single larva recently dead of the disease is sufficient to produce quite a large amount of sacbrood in a colony.

(6) The period from time of inoculation to the appearance of the first symptoms of the disease—the incubation period—is approximately six days, being frequently slightly less.

(7) By inoculation the disease may be produced at any season of the year that brood is being reared.

(8) The disease is more often encountered during the first half of the brood-rearing season than during the second half.

(9) It occurs among bees in localities having as wide a range of climatic conditions, at least, as are found in the United States.

(10) The course of the disease is not greatly affected by the character or quantity of the food obtained and used by the bees.

(11) Larval remains recently dead of the disease prove to be very infectious when fed to bees. Dead larvæ which have been in the brood comb more than one month are apparently noninfectious.

(12) Colonies possess a strong tendency to recover from the disease without treatment.

(13) The virus of sacbrood suspended in water and heated to 138° F. (59° C.) was destroyed in 10 minutes. Considering the varying factors which enter into the problem, the minimum temperature necessary to destroy this virus when applied for 10 minutes should

be found at all times to lie somewhere between the limits of 131° F. (55° C.) and 149° F. (65° C.).

(14) When the virus of sacbrood is suspended in honey it may be destroyed by heating the suspension for 10 minutes at approximately 158° F. (70° C.).

(15) The virus resisted drying at room temperature for approximately three weeks.

(16) The virus when dry was destroyed by the direct rays of the sun in from four to seven hours.

(17) The virus when suspended in water was destroyed by the direct rays of the sun in from four to six hours.

(18) The virus when suspended in honey was destroyed by the direct rays of the sun in from five to six hours.

(19) The virus when suspended in honey and shielded from direct sunlight remained virulent for slightly less than one month at room temperature during the summer.

(20) The virus was destroyed in approximately five days in the presence of fermentative processes taking place in 10 per cent sugar solution at room temperature.

(21) In the presence of fermentative processes going on in 20 per cent honey solution at outdoor temperature the virus of sacbrood was destroyed in approximately five days.

(22) In the presence of putrefactive processes the virus remained virulent for approximately 10 days.

(23) The virus will resist ½ per cent, 1 per cent, and 2 per cent aqueous solutions of carbolic acid, respectively, for more than three weeks, 4 per cent being more effective.

(24) Neither carbolic acid nor quinine as drugs should at present be relied upon in the treatment of sacbrood.

(25) Varying factors entering into many of the problems discussed in this paper tend to vary the results obtained. In such problems the results here given must be considered from a technical point of view as being approximate only. They are sufficiently exact for application by the beekeeper, but to insure the destruction of the virus in practical apiculture the time element indicated from these experiments as sufficient should be increased somewhat.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 432

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER December 13, 1916

THE SPIKE-HORNED LEAF-MINER,[1] AN ENEMY OF GRAINS AND GRASSES.

By PHILIP LUGINBILL and T. D. URBAHNS, *Entomological Assistants, Cereal and Forage Insect Investigations.*

CONTENTS.

	Page.
Introduction	1
Synonymy	2
History of the species	2
Food plants	3
Description	5
Distribution	7
Injury to plants by adults puncturing the leaves	7
Injury to plants by mining habits of larvæ	8
Life history	9
Rearing methods	14
Parasitic enemies	15
Preventive measures	16
Bibliography	17

INTRODUCTION.

The leaf-miner *Cerodonta dorsalis* Loew, although known since 1861, has not received much attention from economic entomologists, probably for the reason that to the present time, so far as known, it has not proved a serious pest, owing to the activity of its parasites and to its wide range of food plants. Although known in entomological literature as "a corn leaf-miner," it has been observed lately that the larvæ work as readily in barley, millet, wheat, and various grasses; in fact, in the rearing cages as well as in the field the leaf-miners prefer barley and millet to corn. Wheat and oats may also be included in the list of food plants, and young barley and oats infested with this species may die from the injury. Oats and barley plants infested with *Cerodonta dorsalis* present a similar appearance to those infested with *Meromyza americana* Fitch or other species of Oscinidæ, and it is possible that injury formerly attributed to the work of Meromyza was in reality the work of *C. dorsalis*.

[1] *Cerodonta dorsalis* Loew; order Diptera, family Agromyzidae.

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SYNONYMY.

This species was first described by Panzer (1)[1] as *Chlorops denticornis*, it being wrongly placed in the genus Chlorops, and in the year 1835 was referred to the genus Odontocera by Macquart (2). In the year 1861 Rondani changed the generic name from Odontocera, which was preoccupied, to Cerodonta (3) (in error published "Cerodontha"). The generic name Ceratomyza was used for this leaf-miner by Schiner (4, p. 434) in 1862, this being a synonym for Cerodontha Rondani.

HISTORY OF THE SPECIES.

So far as could be ascertained from reference to specimens in the National Museum collections, and Bureau of Entomology notes, this leaf-miner was reared, by F. M. Webster, in September, 1884, for the first time in this country, from volunteer wheat plants that sprang up after harvest and near which adults had been captured earlier in the same month. It was also swept with other wheat flies from fields of growing wheat, during the period from November 13 to 15, 1884. The species was reared by Webster from mines in the leaf sheaths of young wheat, July 30, 1888; and on August 24, and again on October 12 of the same year, he reared adults from larvæ found mining the leaves of timothy. From wheat plants taken by him July 7, 1890, at La Fayette, Ind., and shipped to the Bureau of Entomology, adults were also reared by Mr. Theodore Pergande. On February 24 to 28, 1891, Webster swept it from a field of growing wheat at College Station, Tex. During the season of 1894 Dr. W. E. Britton (5), of the Connecticut Agricultural Experiment Station, reared the species from mines in the leaves of corn which was being grown under glass for vegetation experiments. During December, 1897, at Wooster, Ohio, the adults were again reared by Webster from young wheat plants. Dr. A. D. Hopkins (7) reared the fly from timothy at Morgantown, W. Va., in 1898, the larvæ doing considerable damage to this grass.

On June 26, 1905, Webster reared this species from bluegrass growing along the street parking in Aurora, Ill. Flies were reared from wheat plants collected at Lincoln, Nebr., December 9, 1904, by Geo. I. Reeves, and he swept them from young wheat at Wichita Falls, Tex., April 16, 1905. Wildermuth reared it from wheat at Groveport, Ohio, during the summer of 1909. It was sent by W. V. Reed, April 2, 1909, from Cornelia, Ga., where the larvæ were observed attacking growing rye. During 1910, adults were swept in June and July from alfalfa in fields on the college farm at Pullman, Wash., by J. A. Hyslop. In 1911 it was reared, June 9, from a pupa found in a

[1] Numbers in parentheses refer to "Bibliography," p. 17.

stem of wheat, June 1, at Nashville, Tenn., by Geo. G. Ainslie, and was reared by him the same year from mines in leaves of corn at Hurricane, Tenn. During the period from July 23 to September 7, C. N. Ainslie reared it from leaf mines in timothy collected along the banks of ditches about Ely, Nev., September 1, and also from mines in the leaves of Hordeum at Salt Lake City, Utah, during the following September, and again from the same material early in March, 1912.

During 1911 the senior author reared it from leaves of *Panicum miliaceum* at La Fayette, Ind., and followed the species o nthe same plant from June 4 to July 29, 1912, when he was transferred elsewhere, after which the work was continued throughout the remainder of the season by W. J. Phillips. This was the first attempt made to study the development of the species continuously throughout the year. During June, 1913, G. G. Ainslie found a number of mines in the leaves of corn at Nashville, Tenn. All the mines were empty save one, which contained a hymenopterous parasite of this species. On July 7, at the same place, he found a larva mining in crab grass (*Eleusine indica*), which pupated on the same day and became adult on July 17. During 1913 V. L. Wildermuth and R. N. Wilson made some observations on the life history of this species (March to November) at Tempe, Ariz. The senior author again continued his study on the life history of the species at Columbia, S. C., in 1913, from May 4, when larvæ were first found mining in the leaves of corn in the field, until June, when experiments were discontinued for the year, owing to imperfect facilities for continuing the work at that time. In May, 1914, he again took up the investigation and continued the work throughout the remainder of the year.

During February, 1914, the junior author began an investigation of this species in the San Fernando Valley of California, where it was attacking grains. Observations were later extended to the Yuma Valley, in Arizona, and San Joaquin Valley, in central California. Observations on the life history of the species were made in the laboratory at Glendale, Cal., from February to June, and at Pasadena, Cal., from July to April, 1915. Adults and parasites of this species were again reared during March and April, 1914, from mines in leaves of corn at Lakeland and Orlando, Fla., by G. G. Ainslie. Such mines were very common in leaves of corn during this time.

FOOD PLANTS.

This species breeds in a large variety of food plants belonging to the order Graminaceæ. Although it appears to be most frequently found breeding in leaves of corn and barley, it shows a decided fondness for the grasses, especially the millets (*Panicum* spp.), in which it has been found to breed very freely.

In the breeding cages at La Fayette, Ind., the variety known as hog-millet was used by the senior author as a host, and at Columbia, S. C., the variety known as golden millet was used exclusively during the hot summer months, corn in early summer, and oats and rye during late summer and fall.

At Tempe, Ariz., Wildermuth and Wilson used wheat as the host plant in their life-history studies, while at Glendale and Pasadena, Cal., the junior author used barley plants in the life-history studies of the species.

The following is a list of food plants from which adults of *Cerodonta dorsalis* have been collected or reared, showing locality, date, and by whom recorded:

ALFALFA:

Pullman, Wash., June 9, 1910. (J. A. Hyslop.)

BARLEY:

Salt Lake City, Utah, 1911–12. (C. N. Ainslie.)
Tempe, Ariz., June 21, 1913. (R. N. Wilson.)
Glendale, Cal., February to May, 1914. (T. D. Urbahns.)
Pasadena, Cal., August, 1914, to April, 1915. (T. D. Urbahns.)
Tulare, Cal., May 15, 1914. (T. D. Urbahns.)
San Bernardino, Cal., May 27, 1914. (T. D. Urbahns.)
Santa Ana, Cal., April 10, 1915. (T. D. Urbahns.)
Heber, Cal., April 15, 1915. (T. D. Urbahns.)
Yuma, Ariz., April 16, 1915. (T. D. Urbahns.)
Bakersfield, Cal., May 22, 1915. (T. D. Urbahns.)

CORN:

Urbana, Ill., 1915. (S. A. Forbes.)
Hurricane Mills, Tenn., September, 1911. (G. G. Ainslie.)
La Fayette, Ind., 1912. (P. Luginbill.)
Columbia, S. C., 1913 and 1914. (P. Luginbill.)
Nashville, Tenn., June 10, 1913. (G. G. Ainslie.)
Lakeland and Orlando, Fla., 1914. (G. G. Ainslie.)
Glendale, Cal., May 5, 1914. (T. D. Urbahns.)
Yazoo City, Miss., May 17, 1914. (H. E. Smith.)
Greenwood, Miss., May to August, 1914. (H. E. Smith.)
Jackson, Miss., May 15, 1914. (H. E. Smith.)

EGYPTIAN MAIZE:

Glendale, Cal., June 23, 1914. (T. D. Urbahns.)

GRASSES:

Bluegrass (*Poa* sp.), Aurora, Ill., June 26, 1905. (F. M. Webster.)

Hordeum sp.—

Salt Lake City, Utah, 1911, and March, 1912. (C. N. Ainslie.)
Tempe, Ariz., June 21, 1913. (R. N. Wilson.)

Eleusine indica—

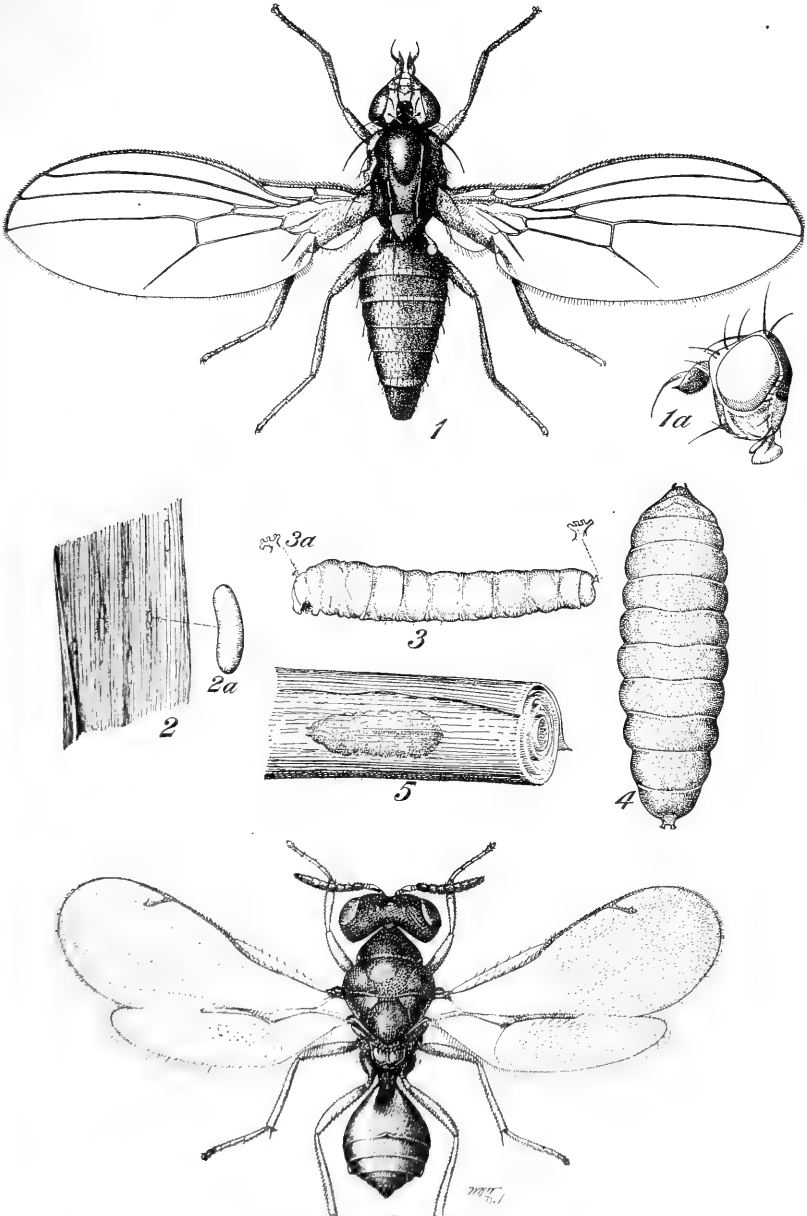
La Fayette, Ind., 1912. (P. Luginbill.)
Nashville, Tenn., July 7, 1913. (G. G. Ainslie.)
Columbia, S. C., August, 1914. (P. Luginbill.)

Hordeum murinum—

Glendale, Cal., April 13, 1914. (T. D. Urbahns.)

Elymus glaucus—

Glendale, Cal., May 3, 1914. (T. D. Urbahns.)



THE SPIKE-HORNED LEAF-MINER (CERODONTA DORSALIS).

FIG. 1.—*Cerodonta dorsalis*: Adult female, dorsal view, greatly enlarged. *1a*, Head of same, lateral view, showing tooth or horn at tip of antenna, more enlarged. FIG. 2.—Section of leaf blade showing eggs in situ and also young larvæ beginning their mines, slightly enlarged. *2a*, Egg, greatly enlarged. FIG. 3.—Larva, lateral view, much enlarged. *3a*, Anterior stigmal process, more enlarged. FIG. 4.—Puparium, dorsal view, greatly enlarged. FIG. 5.—Section of barley stem, showing usual position of puparium beneath leaf sheath. FIG. 6.—*Polycystus foersteri*, a hymenopterous parasite of *C. dorsalis*; dorsal view, very greatly enlarged. (Original.)

GRASSES—Continued.

Bromus carinatus—

Glendale, Cal., May 3, 1914. (T. D. Urbahns.)

Phalaris minor—

Glendale, Cal., June 9, 1914. (T. D. Urbahns.)

Panicum dichotomiflorum—

Owensboro, Ky., September 22, 1913. (G. G. Ainslie.)

Panicum miliaceum—

La Fayette, Ind., 1911; June 4–July 29, 1912 (P. Luginbill).

Dactylis glomerata—

La Fayette, Ind., July 23, 1913. (P. Luginbill.)

MILLET (*Panicum* sp.):

La Fayette, Ind., 1911–12. (P. Luginbill.)

Columbia, S. C., 1914. (P. Luginbill.)

OATS:

Glendale, Cal., May 3, 1914. (T. D. Urbahns.)

Pasadena, Cal., August, 1914. (E. L. Barrett.)

Columbia, S. C., October, 1914. (P. Luginbill.)

RYE:

Cornelia, Ga., April 2, 1909. (W. V. Reed.)

Columbia, S. C., October, 1914. (P. Luginbill.)

SORGHUM:

Columbia, S. C., August, 1914–15. (P. Luginbill.)

TIMOTHY:

La Fayette, Ind., August 14, 1888. (F. M. Webster.)

West Virginia, 1898. (A. D. Hopkins.)

Ely, Nev., September 1, 1911. (C. N. Ainslie.)

La Fayette, Ind., July 12, 1912. (P. Luginbill.)

WHEAT:

La Fayette, Ind., November, 1884; July, 1888; and July, 1890. (F. M. Webster.)

Oxford, Ind., September 5, 1884. (F. M. Webster.)

Lincoln, Nebr., December 8, 1904. (G. I. Reeves.)

Wichita Falls, Tex., April 16, 1905. (G. I. Reeves.)

Groveport, Ohio, date unknown. (V. L. Wildermuth.)

Nashville, Tenn., June 9, 1911. (G. G. Ainslie.)

Tempe, Ariz., March to June, 1913. (Wildermuth and Wilson.)

Elk Point, S. Dak., July 8, 1913. (C. N. Ainslie.)

Visalia, Cal., May 15, 1914. (T. D. Urbahns.)

Tulare, Cal., May 16, 1914. (T. D. Urbahns.)

DESCRIPTION.

THE ADULT.

Cerodonta dorsalis (Pl. I, fig. 1) was redescribed by Mr. J. R. Malloch (14, p. 331), then assistant in the Bureau of Entomology. The description is as follows:

Male and female: Frons yellow, opaque, in breadth about one-half that of head; orbits sometimes blackened, very narrow, on upper half each not over one-sixth as wide as center stripe; three distinct orbital bristles present, and on lower portions a few short hairs; proclinate ocellar bristles parallel, or slightly divergent, separated at base by as wide a space as posterior ocelli; antennæ yellow, third joint black, one and one-half times as long as broad ending in a thorn-like point on upper side; arista black, distinctly thickened at base and tapering to near its middle, pubescence indistinguishable, length of arista short of twice the length of antennæ; face yellow, slightly concave, central keel rounded; cheeks yellow, higher posteriorly than anteriorly, and at highest point about one-half as high as eye, marginal bristles distinct; vibrissa strong, differentiated from marginal bristles; proboscis and palpi yellow; occiput unprojecting on upper half. Mesonotum with disk entirely glossy black, with sometimes an indication of grayish pollen, or with the central portion in front of scutellum yellow, more rarely with two narrow black stripes on sides, and the central yellow portion carried forward at its anterior margin, slightly beyond middle, as narrow lines which more or less distinctly intersect the broad discal black mark, giving the disk the appearance of having five stripes, or a pattern somewhat similar to that of *Agromyza melampyga;* lateral margins of mesonotum broadly yellow; humeri with a black spot; four pairs of dorso-central bristles on mesonotum; no setulæ on disk; pleuræ yellow with black variegations; squamæ yellow, the fringe brownish or grayish; scutellum all black or with the disk yellow, two scutellar bristles present. Abdomen from almost entirely yellow to almost entirely black, posterior margins of segments narrowly yellow. Legs slender, yellow, sometimes with fore tibiæ and tarsi blackened, all tarsi brownish. Wings as figure.

Length 2–2.5 mm.

The stages of this species are as follows:[1]

THE EGG.

(Pl. I, fig. 2, *a*.)

Egg elongate kidney-shaped, rounded at each end. Color opaque white, without distinct punctation, markings, or ornamentation of any kind. Two or three days after deposition the embryo, as seen through the chorion, shows 14 segments.

Length 0.40 mm; diameter 0.18 mm.

THE LARVA.

(Pl. I, fig. 3, and Pl. II, figs. 1 and 2.)

Length 4 mm; greatest diameter 0.75 mm. Slender, nearly cylindrical, slightly thicker near cephalic end, which is obtusely pointed. Mouth-hooks black and exposed to view when at rest. Body segments plainly defined, armed at either end near sutures with slender areas of microscopic spinous processes. Anal extremity abruptly truncate and bearing the spiracular appendages close to the dorsal line. Anterior stigmatal projections plainly visible and formed as in figure 3, a. Color of body in life dirty white, the surface of the skin having a distinct gloss, as shown in figures 7 and 8; after death and preserved in alcohol, opaque, nearly white.

THE PUPA.

(Pl. I, fig. 4.)

Pupa somewhat elongate, flattened dorso-ventrally. White when freshly formed, turning yellow and growing darker as pupa advances in development. Cephalic end obtusely conical; posterior end more rounded. Segments strongly constricted at sutures. Stigmatal processes, both anterior and posterior, distinctly projecting. Length 2.5 to 3 mm.; lateral diameter about 1 mm.; dorso-ventral diameter 0.60 mm. to 0.70 mm.

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[1] The descriptions were written by W. R. Walton.

DISTRIBUTION.

This species has a wide range of distribution within the United States (fig. 1). It is known to occur from Indiana and Ohio in the North to southern Florida in the South, and from Massachusetts in the East to Washington, California, and New Mexico in the West. It is probably to be found wherever its food plants thrive. Outside of the United States it has been collected from Porto Rico and Mexico.

The following localities and other data have been compiled from pinned specimens of this species in the United States National Museum collection: Beverly, Mass., August, 1911 (Burgess); Las Vegas,

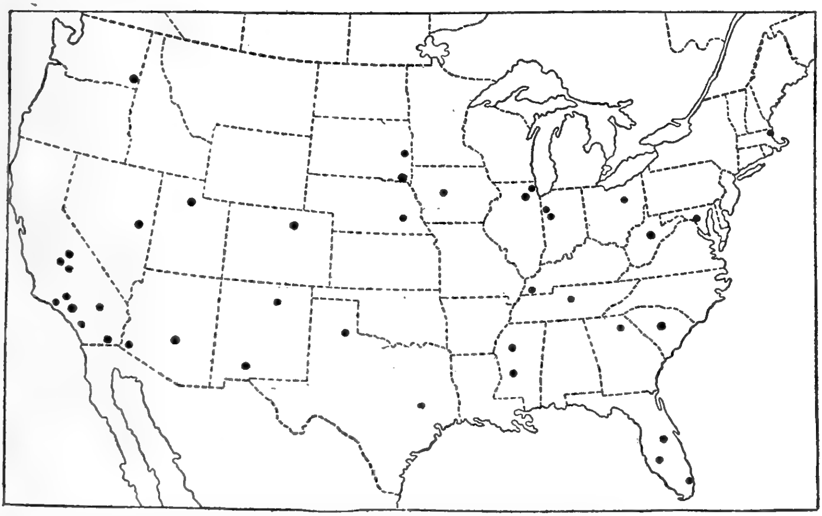


FIG. 1.—Map showing records of distribution of the spike-horned leaf-miner (*Cerodonta dorsalis*) in the United States. (Original.)

N. Mex. (H. S. Barber); Ames, Iowa, June, 1877; Orizaba, N. Mex., January (H. Osborn); Colorado; High Island, Md., May, 1898 (Currie); New York, July, 1898; Arroyo, Porto Rico, February, 1899 (Busck); District of Columbia; Claremont, Cal. (Baker); Biscayne, Fla. (A. Slosson).

INJURY TO PLANTS BY ADULTS PUNCTURING THE LEAVES.

The punctures made by the females of this species in leaves of plants on which they feed and oviposit (Pl. II, fig. 3) resemble very closely those made by females of *Agromyza parvicornis* Loew, with the exception that they are frequently somewhat longer and a trifle narrower. Some of the punctures are twice as long as others. The punctures are not made solely as receptacles in which to deposit eggs, but apparently primarily as a means of acquiring access to the sap of the leaves upon which the adults subsist. Only a very small proportion of the punctures are utilized as receptacles for eggs, which fact would indicate that they are made for feeding purposes rather than for oviposition.

As a general rule, the punctures are made from the upper side, in the tenderest portions of the leaves of recent growth. Sometimes, however, punctures may be found even in the upper part of the tender stems, especially in the case of young plants.

The female adult of this species apparently first scars the leaf surface with her ovipositor. Then, as the sap begins to escape from this wound, the insect proceeds to feed and, with a rasping movement of the mouth parts, digs little furrows between the leaf veins. These feeding punctures are mostly in the form of furrows from 1 to 3 mm. in length and 0.5 mm. wide. Seven adults placed upon young barley plants covered by a lamp chimney made 918 feeding punctures in five days. All of these were on the upper surface of the leaves. Another newly emerged female made 133 feeding punctures on the upper leaf surfaces in a period of seven days.

When leaves of young plants are extensively punctured they presently begin to assume a pale yellow, sickly appearance, first at the tips, but gradually extending down toward the base to the stem, and finally they curl up and wither away. When more than one leaf or if a majority of the leaves of the same plant are injured to this degree by the punctures, the whole plant may die from the injury or produce an inferior, worthless plant.

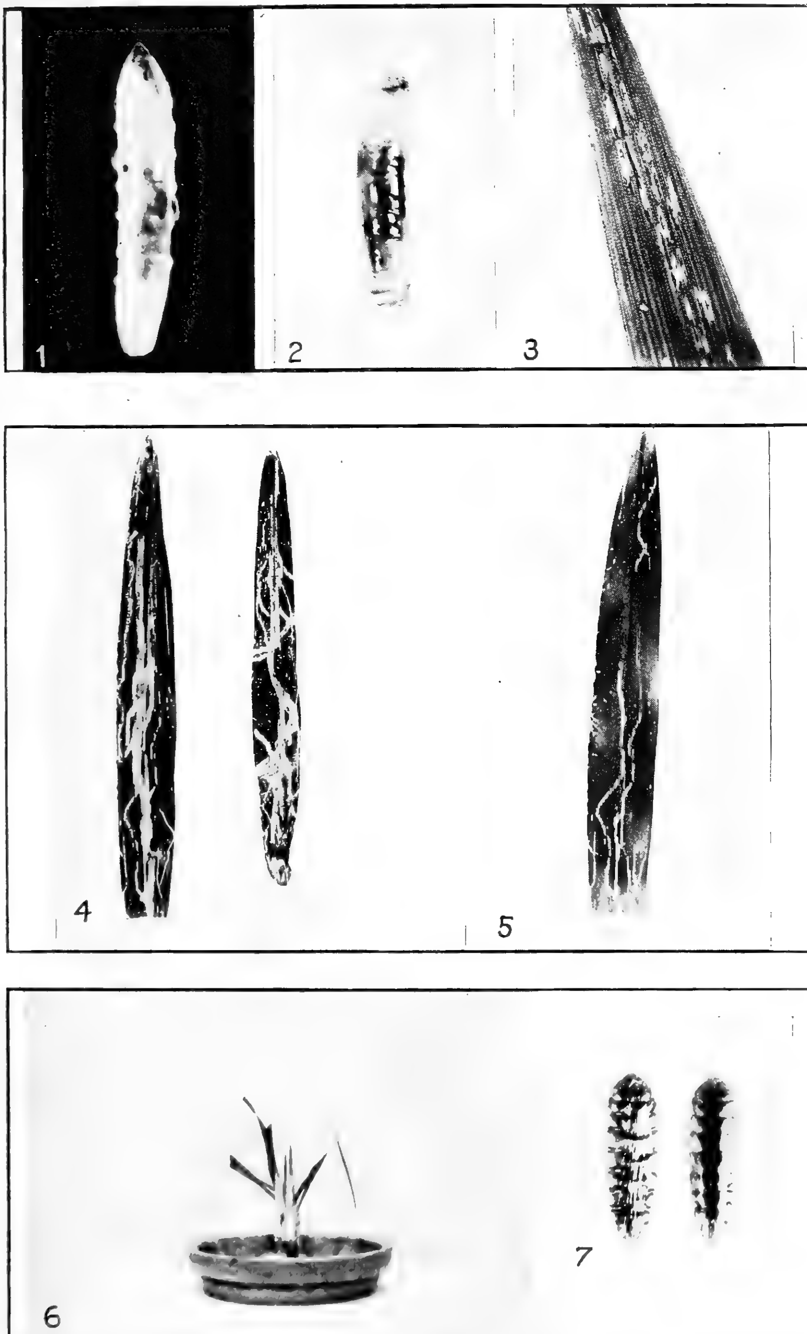
Older plants, as a rule, do not suffer from damage caused by females puncturing the leaves, as they have considerably more leaf surface and sufficient vitality to withstand the injury.

INJURY TO PLANTS BY MINING HABITS OF LARVÆ.

This species has been found to be most destructive in the larval stage, mining in the leaves and sometimes in the stems of young tender plants having only a limited area of leaf surface. Mines started in the leaves of such young plants are often continued down into the heart after reaching the base of the leaf to a point near or slightly below the surface of the ground before the larvæ reach maturity and their ravages cease. The leaves arising from the bud having been severed, they dry up, and the whole plant presents an appearance as though infested with the wheat bulb-worm (*Meromyza americana* Fitch) or some species of the genus Oscinis.

Young tender oat plants about 3 inches tall, having from three to four leaves, were found by the senior author to be injured in this manner in a small patch of oats at Columbia, S. C., in the fall of 1914.

The larvæ of *C. dorsalis* have been observed by the junior author causing much injury to small barley plants in the fields in several



THE SPIKE-HORNED LEAF-MINER (CERODONTA DORSALIS).

FIG. 1.—Larva, dorsal view. Photographed from life. The young larva of an external hymenopterous parasite may be seen attached to middle of larva of Cerodonta on the right, much enlarged. FIG. 2.—Larva, lateral view, from life, showing polished surface and contents of alimentary canal, much enlarged. FIG. 3.—Tip of barley leaf, showing feeding punctures made by adult fly, much enlarged. FIG. 4.—Leaf blades showing advanced work of the larvæ, about natural size. FIG. 5.—Leaf blade, showing mines of young larvæ, about natural size. FIG. 6.—Type of rearing cage used in rearing the larvæ of *C. dorsalis*. FIG. 7.—Puparia, dorsal and ventral views, much enlarged. (Original.)

localities of southern California. The larva, hatching from an egg deposited near the tip of the leaf blade, begins burrowing between the upper and lower epidermal layers of the leaf.

During its first day in that stage it makes a burrow from 5 to 17 mm. in length, directed toward the base of the leaf. After two or three days of burrowing it frequently pursues a zigzag course within the leaf, thereby cutting off the sap supply. In the course of about four days the length of the burrow may reach from 4 to 6 inches. The larvæ soon enter the leaf sheath and in small tender plants burrow into the center of the stem, killing that particular stool or the entire plant.

Up to the present time this species has never been recorded as a serious pest of agricultural crops. The most severely infested field observed by the junior author was one of barley at Yuma, Ariz., on April 16, 1915, in which about 5 per cent of the plants had one or more of the leaves mined by larvæ of Cerodonta.

At Tulare, Cal., both wheat and barley fields showed that about 2 per cent of the plants were infested by this species on May 16, 1914.

In older plants, with more leaf surface and less tender stems, the larvæ, after reaching the base of the leaf, will not enter the stems, but proceed down the sheath. The hearts of such plants are not injured, and consequently the damage inflicted is very small in comparison with that upon young tender plants. However, if a plant has a number of larvæ mining in the leaves, considerable injury may be done. The mines traversing the leaves from tip to base (Pl. II, fig. 4), from one side to the other, have a tendency to interfere with the sap flow of the leaves, which eventually turn yellow and die. In long leaves, such as those of older corn plants, the mines in the leaves frequently reach from 15 to 20 inches in length before the larva is fully developed.

LIFE HISTORY.

OVIPOSITION.

The act of oviposition has been observed upon the leaves of millet by the senior author at Columbia, S. C.; upon wheat by Wildermuth, at Tempe, Ariz.; and upon barley by the junior author at Glendale, Cal. The general method of oviposition is very similar on these three different food plants.

The female fly selects a suitable place for oviposition, usually near the tip of the leaf or along the edge. With head elevated and tip of abdomen lowered, the body is held almost perpendicular to the leaf surface, and by rapid piercing movements of the abdomen the epidermal leaf tissue is punctured. The ovipositor is then forced by repeated thrusts to its full length between the upper and lower layers of the leaf, the egg quickly deposited, and the ovipositor withdrawn to its normal position. The time occupied in oviposition varies from 10 seconds to 1 minute. The entrance to the puncture appears to be left open, although frequently the epidermal tissue about the puncture collapses, partly closing it.

Only one egg is deposited in a puncture, but the fly repeats the process of oviposition a number of times in a given day. Frequently she oviposits into what are apparently small feeding punctures.

The eggs of this species are not as easily detected by the naked eye as are those of *Agromyza parvicornis* in corn, and *A. angulata* Loew in timothy. They are more of a pale white than the eggs of either of the other species and, consequently, are not so conspicuous against the background.

The flies feed and oviposit during all hours of the day. The majority of the eggs, however, are deposited between the hours of 11 a. m. and 4 p. m. during the time the adults are most active.

Eggs may be deposited either from the upper or lower side of the leaves, but the majority of them are deposited from the upper side. They are placed with the longer axis of the egg parallel to the veins of the leaves, as are the eggs of *Agromyza angulata* and *A. parvicornis.* (Pl. I, fig. 2, shows an egg in situ in leaf.)

In the rearing cages eggs are deposited at or near the tips of the leaves, along the margins, near or at the base, in the sheaths, and sometimes in the upper part of the tender stems, especially in young plants. In nature the eggs apparently are deposited at or near the tips of leaves or along the margins of the lower leaves, as mines invariably are found to start from one of these points.

EGGS DEPOSITED BY ONE INDIVIDUAL.

The females of this species, if they have been fertilized, begin to oviposit in from one to six days after emerging from puparia; if unfertilized, they do not usually oviposit.

The laboratory observations of the senior author, made at Columbia, S. C., showed that a single individual deposited as many as 24 eggs in leaves of millet within a period of 24 hours. On an average, nine eggs were deposited per day. The rate of oviposition varied greatly and ranged from one or two eggs on a given day to as many as 15 or 20 eggs on the following day. The maximum number during the life of an individual was 188 eggs, and the longest period of oviposition covered by one individual was 33 days.

At Tempe, Ariz., Mr. Wildermuth recorded 105 eggs deposited by a single individual in leaves of wheat in a period of 10 days. The greatest number deposited in a single day was 27 eggs.

In California the observations of the junior author showed 61 eggs deposited in leaves of barley plants during the life of one individual.

From the observations made in widely separated localities by both the senior and junior authors, it appears that about 60 per cent of the eggs deposited are fertile.

EGGS DEPOSITED IN ONE LEAF AND ONE PLANT.

In our breeding experiments at Columbia, S. C., 28 eggs have been found in a single leaf of millet 6 inches tall, and as many as 50 eggs in an 8-leaved plant; 39 in a 6-leaved plant; and 99 in a 9-leaved plant. It can be seen very readily that even in case some of the eggs are infertile or for other reasons do not hatch, the plants thus heavily infested will be completely destroyed by the larvæ.

INCUBATION OF EGGS.

At Tempe, Ariz., Mr. Wildermuth's records made during the month of April showed the period of incubation to vary from 5 to 9 days, with an average of about 6 days. At Columbia, S. C., the senior author's observations during July and August showed this period to vary from 3 to 5 days, with an average of about 3½ days; one egg, however, was found to hatch in 54 hours (2.2 days). In the fall this period was found to vary from 4 to 8 days, with an average of about 5 days. At Glendale, Cal., the junior author made observations during the month of March which extended this period from 7 to 12 days, with an average of 10½ days. Observations continued during both winter and summer months at Glendale and Pasadena, Cal., showed the incubation period to vary from 5 to 12 days, with an average of about 7 days. This period is without doubt somewhat shorter in the open fields where infested plants are subjected to refracted heat.

LARVAL HABITS.

The larva, when ready to emerge, ruptures the cephalic end of the eggshell, as do the larvæ of *Argromyza angulata* and *A. parvicornis*, and immediately begins to feed on the green tissues of the leaf. The mine at first is very small and threadlike, scarcely noticeable to the unaided eye: (Pl. II, fig. 5.) The diameter of the mine increases as the larva increases in size, and by the time the larva reaches maturity the mine may be greatly widened. In large plants, with long, wide leaves, the larvæ frequently make mines from 15 to 20 inches in length. Such mines are usually linear in outline, and although they run from side to side, the turns are less frequent than when larvæ mine in short leaves of smaller plants. In the latter the larvæ traverse the leaves oftener. They frequently make side galleries diagonally across the leaves, then retreat and continue the main mine down the blade.

A number of these galleries are often found leading away from one mine in a leaf. All sorts of peculiarly shaped mines are made in leaves, especially in small plants or in plants with a limited amount of leaf surface. Some of these mines show almost perfect loops, while others traverse the leaves in snakelike fashion.

In young oats and barley the larvæ apparently break away from the accustomed habit of making threadlike mines and instead appear to undermine almost the entire upper surface of the leaves in which they are feeding. As a result the leaves dry up (Pl. II, fig. 4).

The larvæ of this species pupate in the mines, usually in the leaf sheath (Pl. I, fig. 5). The adult, upon emerging from the puparium, tears open the dry tissue at or near the pupal case and makes its escape.

LENGTH OF LARVAL STAGE.

The average length of the larval stage in the latitude of Columbia, S. C., is 10 days during midsummer or in seasons of high temperatures. This period is considerably longer in spring, and much longer in late fall, ranging from 9 to 24 days during different seasons and in different localities.

Larvæ hatching from eggs about the middle of October were overtaken by frost and killed the second week in November. Larvæ hatching from eggs deposited the same day by the same fly sometimes show a difference of three days in their total period of larval development. The difference is apparently caused by a deficiency in the immediate supply of food, which forces the larva to mine a greater area to satisfy its demand, and as a result the duration of the period of larval development is lengthened.

LENGTH OF PUPAL STAGE.

The length of the pupal stage (Pl. I, fig. 4; Pl. II, fig. 7) of this insect varies from 9 to 12 days during midsummer and from 11 to 16 days during spring and late fall in the latitude of Columbia, S. C.

A short pupal period of eight days during July is recorded by G. G. Ainslie at Nashville, Tenn., and a pupal period of from 14 to 18 days by V. L. Wildermuth at Tempe, Ariz., during March and April. At Pasadena, Cal., the pupal period ranges from 12 to 24 days at different seasons of the year.

LIFE AND HABITS OF ADULTS.

Flies begin to issue from puparia during the latter part of May in the latitude of La Fayette, Ind., but probably considerably earlier at Columbia, S. C., as adults in breeding cages began to issue in February of 1915. These, however, died within a short time and without reproducing. In the vicinity of Pasadena, Cal., adults of this species are active throughout the entire year, appearing in abundant numbers over the grain fields during the months of February, March, and April. The males do not live quite as long in the rearing cages as do the females. They may live from eight days to four weeks, but generally not over two weeks. The females may live from three to five weeks and oviposit during most of this time. This long period of oviposition accounts for the complete overlapping of the broods. The first progeny may have progressed to the pupal stage some days before the last eggs of its mother have been deposited. The females live only from three to five days after they cease to oviposit.

The flies appear the most active when the temperature ranges between 85 and 95 degrees F., and when below 70 degrees they become sluggish in their movements, especially so in flight.

Adults are fond of sweets and lived for a longer period in cages supplied with a quantity of sugar solution than in cages not so provided.

MATING.

Adults generally begin to mate the second or third day after emergence; sometimes mating occurs on the day of issuance. They apparently mate several times during life. They remain in copula from a few seconds to thirty minutes or more. The female is able to fly about while in coitu with the male, the added weight being apparently no great hindrance in flight.

NUMBER OF GENERATIONS.

According to the rearing experiments conducted by the senior author at La Fayette, Ind., there are at least three generations from about the middle of May to the first of October, after which the species goes into hibernation. He found apparently six generations in the latitude of Columbia, S. C. Many of the larvæ of the last generation at both places did not reach maturity. Some died upon maturity of the plants and others were killed by frost.

Rearing experiments in the vicinity of Pasadena, Cal., show that there are at least eight generations of this insect throughout the year. The first and second generations are generally well defined, but the others overlap completely, so that all stages of the insect may be present at one time. In southern California it may be found in all stages throughout the entire winter.

LIFE CYCLE.

The average life cycle in the vicinity of Pasadena, Cal., is considerably longer than in the vicinity of Columbia, S. C., because in the former locality the insect reproduces throughout the winter months, when the stages are very slow in development. The average period elapsing between the different stages throughout the year in the vicinity of Pasadena is as follows:

	Days.
Period between emergence of adult and oviposition	3
Egg stage	7
Larval stage	16
Pupal stage	18
Average life cycle	44

Observations made at Columbia, S. C., from June to August, 1914, showed the stages and life cycle as follows:

	Days.
Period between emergence and oviposition	3
Egg stage	3.5
Larval stage	10
Pupal stage	10
Total life cycle	26.5

Wildermuth obtained the following life cycle of this species at Tempe, Ariz., during April and May in 1913:

	Days.
Period between emergence and oviposition	4
Egg stage	3.5
Larval stage	12
Pupal stage	16
Total life cycle	37.5

HIBERNATION.

This species has apparently no distinct period of hibernation in the warm climate of southern California, but the different stages are naturally considerably retarded in their development during the cold days of winter.

In the latitude of Columbia, S. C., and La Fayette, Ind., the species hibernates in the pupal stage. The first heavy freeze killed the adults, larvæ, and the plants in rearing cages at Columbia, S. C. An infested field of oats at Columbia revealed only puparia throughout the greater part of the winter.

REARING METHODS.

The rearing cages found to be the most satisfactory by the senior author in his study of the life history of this species, both at La Fayette, Ind., and Columbia, S. C., consisted of 12-inch flowerpots containing food plants and covered with cylinders made of celluloid and galvanized iron. The tops of these cylinders were covered with cheesecloth. Moist food was kept in the cages for the adults.

The junior author in his study of this species in California found that cages made of wire arches and cheesecloth bags gave the best results. The type of cage used by him for observations on feeding and oviposition consisted of a lantern chimney covered with cheesecloth and placed over a small potted plant (Pl. II, fig. 6). A lump of sugar moistened with water was placed in the bottom of the cage. The senior author in his study of the oviposition and feeding habits used a cage consisting of a small lantern chimney placed in an earthen saucer. Inside of the lantern chimney was placed a bottle containing a small millet plant in water; these plants were afterward potted. Moistened sugar was also placed in this cage. It was found that adults in the small cages lived for a longer period than in the larger rearing cages, probably on account of having access more readily to food given them.

PARASITIC ENEMIES.

The important natural enemies of this leaf-miner are parasitic Hymenoptera, of which the species named below have been reared. Some of these have been reared at widely separated localities and from their host working upon different food plants. These parasites become active in early spring, increasing in abundance with each succeeding generation, until their activity is retarded by the approach of cold weather.

It may be possible that the almost total disappearance of the host during midsummer in some localities is due to the effective work of some of these parasites, the life histories of which have not been worked out.

Cirrospilus flavoviridis Cwfd.—This species was reared from a mine of *C. dorsalis* in a timothy leaf taken at Ely, Nev., by C. N. Ainslie. It is also a parasite of the leaf-miners *Agromyza pusilla* Meig. and *A. parvicornis.*

Cyrtogaster occidentalis Ashm.—This species was reared by the junior author, on May 9, 11, and 18, 1914, from puparia of *C. dorsalis*, taken from barley leaves at Yuma, Ariz., and again on June 3, 1914, from a puparium which was removed from a leaf of wheat taken at Tulare, Cal. During 1913 the senior author reared it from *C. dorsalis* mines in corn at Columbia, S. C. G. G. Ainslie reared it on May 11, 1914, from *C. dorsalis* mines in corn at Lakeland, Fla., and H. E. Smith reared it May 25, 1914. from mines of this species in corn at Greenwood, Miss.

Diaulinus websteri Cwfd.—This parasite was reared in December, 1914, by E. L. Barrett from larvæ of *C. dorsalis* working in barley at Pasadena, Cal. The species was described by Crawford[1] (p. 184) from specimens recorded from Tempe, Ariz., under Webster No. 7286.

Diaulinopsis callichroma Cwfd.—This species was also reared from *C. dorsalis* larvæ working in corn, first by G. G. Ainslie at

[1] Crawford, J. C. Descriptions of new Hymenoptera. *In* Proc. U. S. Nat. Mus., v. 43, p. 163–188. 1912.

Lakeland, Fla., in May, 1913, and by H. E. Smith at Greenwood, Miss., in May, 1914. The species was described by Crawford[1] (p. 183) from specimens under Webster No. 7286, Tempe, Ariz.

Polycystus foersteri Cwfd. (Pl. I, fig. 6).—This species was reared from *C. dorsalis* in corn by G. G. Ainslie, May, 1913, at Orlando, Fla., and was reared from *C. dorsalis* in barley by E. L. Barrett at Pasadena, Cal., on June 6, 1915. This parasite was described as a new species by Crawford (Proc. U. S. Nat. Mus., v. 45, p. 313) in 1912, from specimens reared by the senior author from *Agromyza angulata* at La Fayette, Ind.

Dacnusa n. sp.—This species was reared April 25, 1914, from a puparium of *C. dorsalis* removed from *Hordeum murinum* taken at Glendale, Cal., and on May 1 and 2, 1914, it emerged from puparia of *Cerodonta dorsalis* removed from barley at the same locality. It was reared on January 3, 1915, by E. L. Barrett from a puparium of *C. dorsalis* removed from a barley leaf at Pasadena, Cal.

Chrysocharus parksi Cwfd.—This species was reared by T. D. Urbahns, the junior author, June 16, 1914, from a puparium of *C. dorsalis* removed from a leaf of wheat taken at Visalia, Cal. The species was described by Crawford[1] (p. 173).

Opius dimidiatus Ashm.—The senior author reared one adult of this species from *C. dorsalis* mines in millet at La Fayette, Ind., in 1912. This species is also recorded as a parasite of *A. pusilla*.[2]

Opius aridus Gahan.—Mr. G. G. Ainslie reared this species from mines of *C. dorsalis* in corn at Lakeland, Fla. This species is also an enemy of *Agromyza pusilla*.[3]

PREVENTIVE MEASURES.

Owing to the concealed character of damage and method of working, this insect has not attracted widespread attention, and no demands have been made concerning control methods. It would appear, however, that the practice of summer fallowing in the West would do much to destroy puparia remaining in the dry leaves.

Fall plowing and, in fact, any thorough cultivation of grain fields to destroy the remaining stems and leaves as well as volunteer grain should destroy such of this species as remain in the larval and pupal stages.

Burning of dry grasses along fence lines, roadsides, and terraces in late fall and early spring should likewise destroy some of the puparia.

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CHANGES IN FRESH BEEF DURING COLD STORAGE ABOVE FREEZING.

By RALPH HOAGLAND, CHARLES N. McBRYDE, and WILMER C. POWICK, *of the Biochemic Division.*

CONTENTS.

	Page.
Hygienic value of cold storage	1
Commercial practices in the cold storage of fresh beef	2
Previous investigations on cold storage of meats	5
Purpose and plan of present investigation	7
Autolysis experiments	8
Cold-storage experiments with fresh beef	29
Effects of cold storage upon the nutritive value of the beef	95
Factors affecting the time that fresh beef can be stored at temperatures above freezing	97
General summary	99
References to literature	100

HYGIENIC VALUE OF COLD STORAGE.

Cold storage is the most efficient method of preserving perishable foodstuffs in their natural condition, or in a state approaching that condition, for various periods of time. It is well known, however, that changes do take place in foodstuffs held in cold storage, and that, roughly speaking, the rate of deterioration or decay, although affected by many factors, is more rapid the higher the temperature. Moreover, the wholesomeness of cold-storage products depends not only upon proper conditions of storage, but also upon the condition of the products when placed in storage and upon the methods of handling subsequent to storage. The hygienic aspect of the cold-storage industry has had an increasing amount of attention during the last few years. There is an increasing need for exact and complete information concerning the changes which take place in foodstuffs held in cold storage, and in regard to the effect of various factors upon the quality and wholesomeness of such products. Much good work has been done but more remains to be accomplished.

COMMERCIAL PRACTICES IN THE COLD STORAGE OF FRESH BEEF.

There are two general methods of handling fresh beef in cold storage, viz, (1) storage at temperatures above freezing, usually between 32° and 38° F., and (2) storage at temperatures below freezing, usually between 8° and 12° F. According to Holmes (1913), 3.1 per cent of the beef slaughtered commercially in this country in 1909 was placed in cold storage at temperatures below freezing, which would leave a remainder of 96.9 per cent that must have been stored at temperatures above freezing. Beef stored at temperatures above freezing is known as fresh or chilled beef. That stored at temperatures below freezing is known as frozen beef. This discussion is concerned only with chilled beef and the methods by which it is handled in the larger meat-packing establishments in this country.

The methods used in the commercial slaughter of cattle are so well standardized that they do not demand special discussion. When the carcass is completely dressed it is split down the back into two equal halves called "sides," which are hung on rails or trolleys. The sides are then washed clean, wiped dry, and run into coolers. In the larger establishments less than an hour is required from the time the animal is stunned until the carcass is placed in the cooler.

REFRIGERATION.

"Coolers" are the names applied to the refrigerated rooms in which carcasses of beef or other meat food animals, or parts thereof, are stored at temperatures above freezing. Meat-packing establishments are usually supplied with two or more coolers for the handling of fresh beef. One of these is known as the "fore cooler," into which the warm beef is run immediately after slaughter, where it is usually held for from 12 to 18 hours until partially chilled. The other is known as the "main cooler," into which the partially chilled beef from the fore cooler is run and then held therein for shipment or other disposal.

The fore cooler is a very important factor in the proper handling of refrigerated beef. When warm beef is placed in a cooler at a temperature of about 32° F., the air soon becomes filled with the condensed-water vapors arising from the warm carcasses unless special provisions have been made for their disposal. If warm beef should be run into a cooler that contained chilled beef the water vapors would condense upon the cold beef and injure its appearance and keeping qualities. Likewise the warm beef causes a considerable rise in the temperature of the cooler, which may increase to 50° F., a temperature which would be injurious to chilled beef held in the same cooler. The temperature of the fore cooler is usually brought down to about 32° F. before filling, though when filled with warm beef it may run up to 50° F.

The main cooler is simply a second cooler into which the partially chilled beef from the fore cooler is run to be thoroughly chilled and held for shipment. In some of the large meat-packing establishments, which have several beef coolers, warm beef is run into one cooler on one day, into another cooler on the second day, and so on, the chilled beef being removed from the first cooler in time for its refilling with warm beef. This practice accomplishes the same result as the use of a fore cooler.

SYSTEMS OF REFRIGERATION.

In commercial meat-packing establishments in this country the ammonia-compression system of refrigeration is used almost entirely. There are, however, a number of methods by which the refrigeration is distributed for the purpose of chilling the coolers. The more important of these are: (1) Closed brine-coil system; (2) sheet-brine system; (3) brine-spray system. In each case the refrigerating agent is sodium chlorid or calcium chlorid brine that has been chilled by the direct expansion of liquid ammonia in closed coils.

Closed-coil system.—Refrigerated brine is pumped through closed coils located in bunkers directly above the coolers. The bunkers are so constructed as to provide for gravity circulation of air, the cold air falling from one side of the bunker into the cooler below and the warm air from the cooler rising at the other side to be refrigerated as it passes over the brine coils. This system also accomplishes a partial drying of the air as it passes over the cold brine coils, which condense a part of the moisture and the dissolved impurities that the air contains. The closed-coil system is the one most commonly used for the refrigeration of fresh-meat coolers.

Sheet-brine system.—This system is similar in principle to the closed-coil system. Instead of passing through closed coils, however, the refrigerated brine is allowed to trickle over a series of suspended muslin curtains located in a bunker room similar to that used in the closed-coil system.

Brine-spray system.—In this system the refrigerated brine is sprayed from a series of pipes located in a bunker room similar to that which is used in the two other systems. One advantage of this system over the other just mentioned is that less head room is required in the bunker room.

When properly installed any one of these systems is considered to give satisfactory results. It is very important, however, that a system of refrigeration for fresh-meat coolers should provide for abundant refrigeration and for a thorough and fairly rapid circulation of air.

CARE OF COOLERS.

The beef cooler is usually one of the most sanitary rooms in a modern packing house. The floor is kept covered with clean sawdust, which is renewed as often as the demands of cleanliness require. Walls and ceilings are usually painted; and if the system of refrigeration has been installed properly they will be free from moisture.

Although a special system of ventilation is not generally installed, beef coolers are as a rule free from objectionable odors. Sufficient ventilation, except perhaps in fore coolers, is usually obtained from the movement of the carcasses in and out of the cooler.

TEMPERATURE OF STORAGE.

The conditions in packing houses differ considerably, but the average temperature for the storage of fresh beef probably lies between 34° and 36° F. It is seldom stored at a temperature below 30° F. or above 40° F.

HUMIDITY OF COOLERS.

As a rule no special means, aside from the use of fore coolers, is used to regulate the humidity of beef coolers. It is recognized that the bunker system for the distribution of refrigeration, properly constructed and with abundance of refrigeration so as to furnish good circulation of air, will keep a cooler in a dry condition. It is well known that beef will keep longer and in better condition in a dry cooler than in one which is moist, the temperature being the same in each case, since moist conditions in a cooler favor the growth of molds and bacteria on the surfaces of meats, and a consequent more rapid deterioration of the product. There seems to be but very little information available concerning the actual humidity of packing-house coolers.

STORAGE PERIOD FOR FRESH BEEF IN COOLERS.

The length of time that fresh beef is carried in cold storage before it reaches the retailer varies considerably among packing houses. It may be said that as a general rule fresh beef is held in cold storage long enough to chill the carcass thoroughly, and that it is then distributed to the trade as expeditiously as practicable or is utilized for the manufacture of beef-food products. Conditions governing the length of time required for the distribution of fresh beef to the retail trade are so various that it would be impracticable to discuss the question in detail. From a general knowledge of the subject, it may be said that the bulk of the chilled beef probably reaches the retailer before it has been in cold storage three weeks.

COMMERCIAL RIPENING OF MEATS.

The term "ripening," or "ageing," as applied to fresh beef, denotes the practice of holding such meat in cold storage at temperatures above freezing for various periods of time for the purpose of improving the quality of the meat, it being the opinion of experts that the ripening of beef greatly improves its quality, particularly as regards tenderness. This practice is not followed to any extent by the larger packing houses on their own account, but it is carried on to a certain extent by concerns which supply meats to high-class hotels and restaurants and to the dining-car service. As a rule, such concerns do not ripen meats in their own coolers, but select their cuts of meat and have them ripened in coolers belonging to the larger packing houses.

The practice of ripening meats is a simple one. Suitable cuts of meat, usually heavy, fancy ribs and loins and occasionally entire hind quarters, are hung in a cooler set aside for the purpose, or in a regular beef cooler, for from two to six weeks, depending upon the degree of ripeness desired. A dry cooler with good circulation of air is preferred, and the temperature is ordinarily held at 34° F. Depending upon the condition of the cooler as regards temperature and humidity, cuts of meat may show a slight growth of mold after from two to three weeks, and a heavy growth after from four to six weeks in storage. The growth of mold appears first and is heaviest on the cut surfaces of the meat. The degree of ripeness is judged largely by the length of the "whiskers," as the growth of mold is called in packing-house parlance. Such meats are wiped free of mold when sold; and the purchaser must assume any loss due to the necessity for trimming. As compared with the total amount of chilled beef handled in this country the quantity of specially ripened beef is quite small.

PREVIOUS INVESTIGATIONS ON COLD STORAGE OF MEATS.

Only a brief discussion of the more important cold-storage investigations will be attempted.

Gautier (1897)[1] was one of the earliest workers to carry on extensive investigations concerning the changes which take place in meats during cold storage. He studied the chemical, physical, and organoleptic properties of fresh (French) beef and mutton as compared with frozen (Argentine) beef and mutton that had been held in cold storage between 5 and 6 months at —3° to —5° C. Artificial digestion experiments were also carried on. In general, the conclusions reached were to the effect that there was little difference in the composition of the fresh beef and mutton as compared with the

[1] References to literature will be found on page 100.

frozen products. Certain physical changes were noted in the frozen meat, viz, slight desiccation, exudation of juice on thawing, and development of a slightly burnt flavor on cooking. It was noted that a slice of frozen meat would not keep as long in the open air at 12° to 18° C. as a slice of fresh meat.

Richardson and Scherubel (1908) conducted an extensive series of experiments concerning the changes which take place in frozen beef during cold storage. Fresh beef was frozen and then stored for periods ranging from 33 to 554 days, at temperatures varying from —9° to —12° C. Samples were examined in the fresh condition and at intervals during the course of the experiment. Chemical, bacteriological, and histological studies were made. The results of these investigations show but slight differences between the composition of fresh and that of frozen meats. On cooking, no difference in flavor was noted between the fresh and the frozen samples of meats. In closing their paper, the authors make the following statement:

> On the whole the results of the various lines of work reported in this paper, chemical, histological, and bacteriological, indicate that cold storage at temperatures below —9° C., at least, is an adequate and satisfactory method for the preservation of beef for a period of five hundred and fifty-four days and probably for a much longer time.

The same authors (1909) conducted a second series of investigations having to do with the changes which take place in fresh beef held in cold storage at temperatures above freezing. Experiments were carried on with pieces of beef known as "knuckles," which were stored in a cooler at temperatures varying from +2° to +4° C. for periods varying from 7 to 121 days. Considerable changes in the composition of the samples were noted as the storage period was increased. Increases were noted in the percentage amounts of total water-soluble solids, total soluble, coagulable, and meat-base nitrogen, but the increases were not regular. Evidences of bacterial activity were apparent early in the investigation.

Emmett and Grindley (1909) studied the changes that occurred in fresh beef stored at temperatures above freezing. Two steers were slaughtered for the experiment; one-half of each carcass was examined in fresh condition and the other two halves were placed in cold storage at 33° to 35° F. Of the two halves placed in cold storage, one was taken out at the end of 22 days and examined, and the other at the end of 43 days. In the case of the beef which had been stored 22 days, the only real changes noted were distinct increases in the total soluble and the soluble inorganic phosphorus, and a decrease in the nonnitrogenous extractives. In the case of the beef stored 43 days the chemical changes were greater in number than in the beef stored 22 days, but were without appreciable effect upon the nutritive value of the meat.

Wright (1912) made a chemical and bacteriological study of fresh and frozen New Zealand lamb and mutton. Carcasses of each class of animals were stored at 2° to 19° F. for periods ranging from 7 to 160 days. Samples were examined chemically and bacteriologically in the fresh condition and at intervals throughout the course of the experiment. The results of these experiments indicate the following changes in the lamb and mutton stored for 160 days at 2° to 19° F.: Loss of moisture amounting to from 2 to 3 per cent; an increase in proteose, peptone, and meat-base nitrogen; and no appreciable change in ammoniacal nitrogen or in the free acidity of the fat. The changes in chemical composition were ascribed to enzym action. The bacterial condition of the frozen meat remained the same as that of the fresh product. When freezing and subsequent thawing were carried on gradually, there was no alteration in the structure of the tissue. The nutritive value of the lamb and mutton was not affected by freezing and storage.

Ascoli and Silvestri (1913) carried on a series of experiments concerning the relative properties of fresh and frozen beef. Fresh, local beef (Italian), and frozen Australian and Argentine beef that had been held in cold storage about two months were used for the investigation. The following ground was covered in the studies with each class of meat: Chemical composition, digestibility in vitro, action on gastric secretion, digestibility with human subject, histological and autolytic changes. Certain changes were noted in the frozen as compared with the fresh meat, viz, a change in color, an increase in soluble protein which exuded in the form of a reddish fluid when the meat was thawed, the development of a peculiar taste, and a decrease in the aromatic odor of the broth. The changes were more apparent in the fat than in the muscular tissue. The changes noted were ascribed to the action of enzyms. The authors concluded that frozen meats may be regarded as a wholesome food product and may be eaten without injury.

PURPOSE AND PLAN OF PRESENT INVESTIGATION.

Purpose of investigation.—This investigation was undertaken with the following objects in view: (1) To study the changes which take place in fresh beef stored at temperatures above freezing, with special reference to the effect of such changes upon the wholesomeness of the product; (2) to determine the causes of the changes which take place in fresh beef held in cold storage under the above conditions; (3) to determine the length of time that fresh beef can be held in cold storage at temperatures above freezing and remain in wholesome condition, with special reference to the effect of various factors upon the length of the storage period.

Plan of investigation.—For the purpose of studying the problems outlined above, three distinct lines of investigation were planned, viz, (1) autolysis experiments with fresh beef, (2) cold-storage experiments with fresh beef, (3) a study of the factors affecting the length of time that fresh beef can be carried in cold storage.

The changes which ordinarily take place in fresh beef, and in other meats as well, during cold storage at temperatures above freezing, may be due to one or more of three causes, viz, (1) enzyms occurring naturally in the meats, (2) bacteria, and (3) chemical and physical agencies.

The action of the first of these agencies in causing changes in meats during cold storage is probably less well understood than is that of the two others, and seemed to call for special investigation.

AUTOLYSIS EXPERIMENTS.

The term autolysis, as applied to animals, is the name given to the post-mortem changes which take place in the tissues or the fluids of the body through the agency of enzyms and in the absence of bacterial action. Under certain abnormal or pathological conditions autolysis may occur in the tissues or fluids of living animals.

The discovery of autolysis is generally accredited to Salkowski (1891), who called the process "autodigestion." Previous investigators had noted the phenomenon but had not appreciated its importance. Salkowski studied the autolysis of the liver and striated muscular tissue of the dog, using chloroform to prevent bacterial action. Since then a very large number of autolysis experiments have been carried on with practically every organ and tissue in the body. For a résumé of the literature on autolysis and intracellular enzyms, the reader is referred to Jacoby (1902), Oswald (1905), and Vernon (1908, 1910).

ASEPTIC AUTOLYSIS EXPERIMENT WITH BEEF.

The object of this experiment was to secure a measure of the various changes which, in the absence of bacterial action and under the most favorable conditions, might be caused in the muscular tissue of beef by the action of the enzyms occurring naturally in that tissue.

METHOD OF PROCEDURE.

Slaughter.—A fat "high-grade" Shorthorn steer was slaughtered at a local packing house by the usual methods. The operation was carried on with as much cleanliness and dispatch as possible, though it was recognized that it would be impossible to carry on the operation under strictly aseptic conditions. On the completion of slaughter one hind quarter was cut from the carcass, wrapped in cheesecloth previously soaked in a solution of bichlorid of mercury (1–1,000) and then in dry cheesecloth and paper, and was at once transported to the laboratory by means of a motor truck, the trip requiring about half an hour.

Preparation of samples.—At the laboratory the hind quarter was transferred at once to a small bacteriological workroom, the floor, walls, and ceiling of which had been sprayed a short time previously with a disinfectant solution. Large plugs of meat, approximating 3 to 4 inch cubes, were cut from the muscular tissue, avoiding connective tissue and fat as much as possible. Sterile instruments were used in taking the samples and great care was exercised to make this procedure as nearly aseptic as possible. In taking the samples the outer portions of the hind quarter which had come in contact with the bichlorid gauze were of course rejected, these portions being trimmed away. The samples, which weighed from 274 to 512 grams, were immediately transferred to sterile crystallizing dishes fitted with glass covers. The dishes were then weighed and the covers sealed with adhesive tape and over the tape were placed strips of tin foil. This was done for the double purpose of preventing evaporation and bacterial contamination from the outside. The dishes containing the samples were then placed in the incubator.

Bacteriological control of experiments.—The samples were carefully inspected from day to day for evidences of bacterial growth. As the moist surfaces of the meat samples and the exuded juices furnished an excellent medium for the growth of contaminating microorganisms, such growths, when they occured, soon became perceptible to the naked eye. Out of a total of 36 samples, 24 showed visible bacterial growths upon incubation and these were rejected. In the case of these samples it was not necessary to make cultures, as the bacterial growths were quite apparent to the naked eye; in doubtful cases stained preparations were made. Nine of the samples showed no visible bacterial contamination after incubation periods ranging from 7 to 100 days, and these were subjected to careful bacteriological examinations in order to establish their sterility. In examining the samples bacteriologically, cultures were first made from the exuded juice and the outer portions of the meat samples. The samples were then cut in half with sterile instruments and cultures taken from the inner portions. Both anaerobic and aerobic cultures were made on several kinds of media. The 9 samples which showed no visible bacterial growths were found to be sterile upon bacteriological examination, and these samples were passed for chemical examination and study.

Sampling of fresh material.—The samples having been taken for incubation, a composite sample of the lean meat was taken for analysis and placed in cold storage until the next day, when it was prepared for chemical examination. Analytical work was started practically 24 hours after slaughter, during which time the material used for analysis had been in cold storage 17 hours. All work in the preparation of the material for analysis, including the weighing of the material for individual determinations, was carried on in a refrigerated room at a temperature between 32° and 40° F. After the fresh material had been ground as finely as possible and transferred to glass jars which were then tightly stoppered, chemical work was started forthwith. In the case of the incubated samples, as soon as cultures had been taken for bacteriological examination, the dishes were again sealed and placed in a refrigerated room at a temperature of 24° F. for 2 or 3 days or until results had been obtained from the bacteriological examination of the samples. The meat was then prepared for analysis by the same methods used with the fresh material.

PHYSICAL AND ORGANOLEPTIC CHANGES.

The sterile samples showed increasing losses in weight as the experiment progressed, ranging from 0.8 per cent in the sample incubated 7 days to 10.08 per cent in the sample incubated 100 days.

Certain observations on changes in the character of the samples during incubation may be of interest. The sample which had been incubated 7 days showed the following characteristics: There was no apparent disintegration of the tissues and the piece of meat had retained practically its original form; considerable juice had exuded which had turned light brown in color and which contained considerable sediment of a grayish-white color; after the dish had been opened and cultures for bacteriological examination had been taken, a strip of moist lead paper was inserted as a test for hydrogen sulphid, but no reaction was obtained; the exposed surface of the meat was light brown in color, while the surface which rested on the bottom of the dish was bright-pink in color. The cutting of a cross section showed that the meat was somewhat rubbery in texture and not noticeably tender. The cross section showed a brown zone extending inward for a distance of about one-fourth of an inch from the surface, except where the meat had rested upon the bottom of the dish, where the pink color extended to the surface. The interior of the sample was of a uniformly bright-pink color. The meat had a pleasant odor, somewhat similar to that of rare roast beef. The remainder of the sterile samples, which had been incubated for periods ranging from 14 to 100 days, showed characteristics so similar to those of the sample just described that a separate description of each sample does not seem to be necessary.

As the incubation period progressed there were some evidences of desiccation. There was no marked softening of the tissues, and there were no apparent evidences of muscular disintegration in any of the samples. The sample incubated 100 days was possibly somewhat more tender than the sample incubated 7 days. All samples showed the brown outer zone and pink interior. With increasing age there was some change in the odor of the samples, the one incubated 100 days having a rather old but not unpleasant odor. The juice that had exuded from the samples appeared to become more watery as the experiment progressed. In the case of some samples where the meat had rested against the side of the dish in such a way as to pocket some of the juice and protect it from the air the juice had a purplish-red color, similar to but more intense than that of the interior of the meat samples, in contrast to the brown color of the juice exposed to the air. The significance of this observation concerning the changes in color of the meat and juice has been discussed by one of the authors in another paper.[1]

A sample which had been incubated 103 days was broiled and sampled by three judges. The consensus of opinion as to the quality of the meat was about as follows: The meat is quite tender and has an old, highly acid, and rather disagreeable flavor which persists in the mouth after eating; the meat is not entirely objectionable but is not appetizing; no ill effects were suffered from eating the meat.

CHEMICAL STUDIES.[2]

The analytical methods used were those which preliminary investigations had shown to be adapted to the work in hand. All determinations were made in duplicate, and except where noted were made upon the original material. Averages of closely agreeing duplicates are reported.

METHODS OF ANALYSIS.

Moisture.—About 5 grams of the finely ground material were weighed from a weighing bottle into a previously weighed bottle cap and placed in a freezing compartment at a temperature of 25° F. At the end of 24 hours the bottle cap and its frozen contents were transferred to a well-chilled desiccator containing sulphuric acid, which was then evacuated to a pressure of from 3 to 5 millimeters. Two days afterwards the samples were removed and weighed, after which the drying in vacuo was continued over fresh concentrated sulphuric acid until a constant weight was obtained.

This method has the merit of guarding the sample against chemical changes during the course of the determination and of leaving the dried substance in a porous condition that greatly facilitates its complete extraction with ether.

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[1] Hoagland, Ralph, Formation of Hematoporphyrin in Ox Muscle During Autolysis. Journal of Agricultural Research, v. VII, p. 41–45, Oct. 2, 1916.

[2] The authors desire to extend their thanks to Mr. Robert H. Kerr for having made the analyses of the fats which are reported in this paper.

Fat.—For the determination of fat, the dried residue from the moisture determination was crushed and exhausted with absolute ether in a Soxhlet apparatus for a minimum of 16 hours. After distilling the ether, the fatty residue was dried and weighed in the usual manner.

Ash.—Three to five grams of the fresh material were weighed into a tared platinum dish and ignited in an electric muffle furnace at a temperature not exceeding 600° C. In this way a light, fluffy, gray ash was obtained without fusing. Preliminary work showed this method to give as accurate results as either the calcium acetate or the charring and extraction method, and to be more convenient.

Total nitrogen was determined by the Kjeldahl-Gunning method, using 3–5 grams of the original material.

Total phosphorus.—With a view to equalizing any possible errors inherent in the methods used, so that the ratio of the inorganic to the total phosphorus might be obtained with the maximum of accuracy, the same method was used for the final estimation of total phosphorus as was employed in the inorganic phosphorus determination. After 6 to 10 grams of the finely ground material had been digested with sulphuric and nitric acids by the well-known Neumann method, the phosphorus was precipitated from the diluted and neutralized solution by a considerable excess of magnesia mixture and a large excess of ammonia. The magnesium ammonium phosphate was then filtered off, dissolved in dilute nitric acid, and reprecipitated and weighed as ammonium phosphomolybdate by the method of Lorenz (1901), (c. f. Neubauer and Lücker, 1912), with observance of all analytical precautions. The results are reported in terms of percentages of the elementary phosphorus.

Ammonia was determined by the well-known aeration method of Folin. The apparatus consisted essentially of a Folin absorption cylinder containing dilute sulphuric acid for the washing of the incoming air, a Hopkins safety bulb for removing any sulphuric acid spray from the air current, a 16-ounce bottle of tall form for the reception of the sample, a 250 c. c. Erlenmeyer flask for safety purposes, and a Folin absorption cylinder containing 10 c. c. of tenth-normal sulphuric acid in which the ammonia was received. The above were all connected in series in the order named, and the receiver was connected with a vacuum system.

About 20 grams of the ground meat were weighed accurately into the tall bottle, suspended in the smallest amount of water practicable, and treated with 50 c. c. of a solution containing 4 per cent sodium carbonate, 0.1 per cent of sodium fluorid, and sodium chlorid [1] to saturation. There was also added 25 c. c. of pure ethyl alcohol, which was replaced as occasion required to prevent foaming. The bottle was then connected in the series and a strong air current was drawn through the apparatus for a period of at least four hours. The excess of standard acid was estimated by titration, carminic acid being added as an indicator. Preliminary experiments had shown that a four-hour aeration period was more than sufficient.

Results are reported in terms of percentages of elementary nitrogen.

Preparation of extract.—Previous investigators who have determined the soluble constituents of muscular tissue have, as a rule, used water as a solvent, although solutions of various salts, of varying degrees of concentration, have been used to some extent. Taking all of the facts concerning the nature of the constituents of muscular tissue into consideration, it was concluded that the use of a solvent isotonic with the muscle serum would throw the most light upon

[1] Folin, O. Journal of Biological Chemistry, v. 8, p. 497.

the nature and quantity of the soluble constituents of the muscles, either in fresh condition or after autolysis or cold storage.

The solvent used was 0.9 per cent aqueous solution of sodium chlorid that had been saturated with thymol by shaking with a concentrated chloroform solution of that substance. The preparation of the extract in these experiments was always begun as soon as possible after the grinding of the samples. The entire process was carried on in refrigerated rooms, the preparation of the extract at a temperature between 34° and 45° F., and subsequent extraction at a temperature between 34° and 36° F. The solvent was cooled to about 34° F. before use.

One hundred grams of the finely ground meat were weighed into a beaker and transferred quantitatively, with the aid of some of the solvent, to a 7-inch porcelain mortar. The meat was mascerated with the solvent to a smooth pulp, and quantitatively transferred to a 2,000 c. c. volumetric flask with the aid of a stream of the solvent from a wash bottle. The contents of the flask were then diluted to the mark with the isotonic solution, and the flask was placed in a cold-storage room at a temperature between 34° and 36° F. The suspension thus prepared was shaken at intervals of not less than an hour during the remainder of the day, and at like intervals during the morning of the following day, until at the expiration of the twenty-third hour it had been shaken on eight different occasions. After settling for another hour, it was filtered, the clear filtrate being used for the determination of the soluble constituents of the meat.

A determination of the volume displaced by the insoluble material has convinced us that the error caused by its presence is negligible.

Total solids were determined by evaporating 50 c. c. of the extract to dryness in a platinum dish on a steam bath, and by subsequently drying to constant weight at 100° C. Correction was made later for the sodium chlorid contained in the extract.

Ash.—The residue from the determination of total solids was carefully charred in an electric furnace, the temperature being kept below 600° C. in order to guard against volatilization of sodium chlorid. The charred mass was extracted with hot distilled water, filtered, washed, and the residue then ignited in the original dish. The filtrate was then transferred to the dish, evaporated to dryness, dried at 150° C. for several hours, and finally ignited for a short time at a temperature under 600° C. The dish was covered during ignition to avoid loss by decrepitation. Correction was made for the sodium chlorid content of the ash.

Sodium chlorid.—The ash was extracted with hot water, the filtrate made to volume, and sodium chlorid was determined in an aliquot portion by means of a standard solution of silver nitrate, with potassium chromate as an indicator.

Organic extract was obtained by substracting the percentage of ash from that of total solids.

Total soluble nitrogen was determined in 100 c. c. of the extract by the Kjeldahl-Gunning method.

Coagulable nitrogen.—One hundred cubic centimeters of extract was transferred to a 150 c. c. beaker, heated on a steam bath until the protein had coagulated, and then neutralized to litmus paper by the addition of a standard solution of sodium hydroxid. The solution was then heated on the steam bath until the original volume had been reduced by about one-third, after which it was filtered and the precipitate washed with hot water until free from sodium chlorid. Nitrogen was then determined in the precipitate.

Proteose nitrogen was determined by the method of Baumann and Bömer (1898). Five hundred cubic centimeters of extract was heated on a steam bath to coagulate the protein, then neutralized to litmus paper by the addition of a standard solution of sodium hydroxid, and finally concentrated to about two-thirds of the original volume. The solution was then transferred to a 500 c. c. flask, cooled, made to volume, and filtered; and 400 c. c. of the filtrate was concentrated on a steam bath to about 30 c. c. Particular care was taken that the solution did not evaporate to dryness. To remove any coagulable protein that might have separated out during the concentration, the solution was filtered and the precipitate washed. The filtrate was then transferred to a 150 c. c. beaker and made up to 50 grams in weight. One cubic centimeter of 1–4 sulphuric acid and zinc sulphate in slight excess of the amount required to saturate the solution were added. The solution was stirred at intervals to insure complete saturation, and after 24 to 48 hours was filtered and the precipitate washed free of sodium chlorid by means of a saturated solution of zinc sulphate acidified with 2 c. c. of 1–4 sulphuric acid to 100 c. c. of solution. Nitrogen was determined in the precipitate.

Amino nitrogen.—The term "amino nitrogen" is here applied to the nitrogen liberated from the noncoagulable portion of the 0.9 per cent sodium chlorid extract by the action of an excess of nitrous acid. Part of this nitrogen may or may not be derived from substances other than amino acids. Certain it is, however, that the greater the degree of proteolysis that a protein substance undergoes, the more nearly will its split products resemble a mixture of amino acids, and the greater will be its yield of free nitrogen when acted upon by nitrous acid. The prime object of this determination, therefore, was merely to obtain in a simple way comparative data as to the degree of proteolysis that had taken place in the various samples as judged by the amounts of nitrogen yielded by their reacting amino groups.

For this purpose 500 c. c. of the extract was measured into a 600 c. c. beaker, heated on a steam bath to coagulate the proteins, and after having been neutralized to litmus paper, was evaporated to about 330 c. c. The solution and coagulum were quantitatively transferred to a 500 c. c. volumetric flask, cooled, diluted to the mark, and filtered. Four hundred cubic centimeters of this filtrate was measured into a suitable beaker and evaporated to about 25 c. c. on a steam bath, after which the concentrated solution was quantitatively transferred to a 100 c. c. beaker and further concentrated to a volume of about 10 c. c.[1] The final concentrate was then quantitatively washed into a 25 c. c. volumetric flask, cooled, diluted to the mark, and filtered to remove any additional coagulum that might have formed. A 10 c. c. aliquot of this filtrate was used for the determination of amino nitrogen.

The amino nitrogen was estimated by the method of Van Slyke (1912) in the apparatus designed for that purpose. The 10 c. c. aliquot mentioned above was introduced into the reaction compartment in the presence of an excess of glacial acetic acid and potassium nitrite and the absence of air; the nitrous oxid and carbon dioxid formed were absorbed from the mixture of gases by means of an alkaline solution of potassium permanganate in a gas pipette and the residual nitrogen was measured in a nitrometer with the customary precautions. Although octyl alcohol was used to reduce foaming in the reaction compartment, it was found impossible to shake the mixture continuously for five minutes as prescribed by Van Slyke. The reaction period was therefore lengthened from 5 to 20 minutes, and the uniform practice was adopted of

[1] An evaporating dish was found to be unsuitable for this purpose, since the solids left upon its walls, as the level of the liquid recedes, are subjected to superheating that may vitiate the results.

shaking the apparatus for 2 minutes each at the beginning, in the middle, and at the end of the reaction period.

The results of this determination are reported in terms of percentages of elementary nitrogen.

Acidity was determined by titrating 100 c. c. of the extract against tenth-normal sodium hydroxid, using phenolphthalein as an indicator. Results are calculated in terms of lactic acid.

Total soluble phosphorus.—For this determination, 100 c. c. of the 0.9 per cent sodium chlorid extract was used. The method of determination was identical with the method used for the estimation of total phosphorus.

Soluble inorganic phosphorus was determined by the method of Chapin and Powick (1915), which consists essentially in the removal of the protein material by means of picric acid and the subsequent double precipitation of the inorganic phosphorus from an aliquot of the filtered picric acid solution, first, as magnesium ammonium phosphate and afterwards as ammonium phosphomolybdate according to the method of Lorenz (1901). "Modification B" of this method was used, no correction being made for the volume of the picric acid coagulum. For the sake of brevity the details of this method must be omitted. A complete description will be found in the original article by Lorenz.

The results are reported in terms of percentages of elementary phosphorus.

Soluble organic phosphorus.—The percentage of soluble organic phosphorus was obtained by subtracting the percentage of soluble inorganic phosphorus from that of total soluble phosphorus.

COMPOSITION OF DIFFERENT MUSCLE BUNDLES FROM A HIND QUARTER OF A STEER.

The original plan for the conduct of the autolysis experiment was to determine the changes taking place in individual bundles of muscles; but in practice it was found in the course of some unreported work that it would be impracticable to obtain a sufficient number of sterile samples by this procedure. This plan was therefore abandoned and it was decided to take the samples for incubation at random from the muscular portions of the round of the hind quarter, and then to determine the composition of the fresh material by analyzing a composite sample taken from many parts of the round.

It was recognized that there might be slight differences in the composition of the different muscle bundles, a fact that would need to be taken into consideration in interpreting the results of an autolysis experiment conducted according to our plan. For this reason the composition of five of the more important bundles of muscles from the round of a fat steer was determined. The quarter of beef had been held in cold storage at 32°–34° F. for 48 hours previous to dissecting out the muscle bundles, and samples prepared for analysis were held in cold storage for an additional period of 24 hours, making a total of 72 hours' storage before analytical work was started.

Tables 1 to 5 inclusive show the composition of five muscle bundles from the hind quarter of the steer. Tables 1 and 3 show the composition of the tissues and of a sodium chlorid extract of the tissues expressed in terms of percentages of the fresh material. On account of the variation in the moisture and fat content of the different muscles that may be noted in Table 1, these two tables do not show the true relative composition of the muscles as well as do Tables 2, 4, and 5, where the results have been calculated to a moisture free and fat-free basis. A detailed discussion of the data in these tables does not seem to be necessary.

TABLE 1.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		Hours.								
100	Semimembranosus muscle	48	74.95	2.21	1.08	3.51	0.0086	0.210	0.167	0.043
101	Biceps femoris muscle	48	75.60	1.89	1.07	3.33	.0088	.208	.161	.047
102	Vastus externus muscle	48	75.56	1.51	1.09	3.38	.0076	.204	.160	.044
103	Semitendinosus muscle	48	75.89	1.81	1.10	3.38	.0093	.206	.164	.042
104	Rectus femoris muscle	48	75.87	1.34	1.09	3.32	.0087	.201	.158	.043

TABLE 2.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		Hours.							
100	Semimembranosus muscle	48	76.64	4.74	15.35	0.0375	0.918	0.733	0.185
101	Biceps femoris muscle	48	77.05	4.75	14.77	.0393	.923	.714	.209
102	Vastus externus muscle	48	76.72	4.75	14.74	.0332	.890	.696	.194
103	Semitendinosus muscle	48	77.29	4.93	15.16	.0418	.922	.735	.187
104	Rectus femoris muscle	48	76.90	4.79	14.57	.0384	.882	.694	.188

TABLE 3.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Noncoagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		Hours.												
100	Semimembranosus muscle	48	7.48	1.16	6.32	0.86	1.001	0.539	0.462	0.029	0.0900	0.167	0.109	0.058
101	Biceps femoris muscle	48	7.42	1.17	6.25	.78	.981	.545	.436	.024	.0896	.161	.099	.062
102	Vastus externus muscle	48	6.84	1.07	5.77	.80	.907	.475	.432	.025	.0864	.160	.106	.054
103	Semitendinous muscle	48	7.15	1.08	6.07	.79	1.001	.551	.450	.019	.0855	.164	.106	.058
104	Rectus femoris muscle	48	6.75	1.02	5.73	.68	.877	.453	.424	.016	.0905	.158	.110	.048

TABLE 4.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen. Total soluble.	Nitrogen. Coagulable.	Nitrogen. Noncoagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Phosphorus. Total soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
		Hours.												
100	Semimembranosus muscle	48	32.73	5.08	27.65	3.77	4.38	2.36	2.02	0.125	0.3940	0.733	0.475	0.258
101	Biceps femoris muscle	48	32.95	5.20	27.75	3.46	4.36	2.42	1.94	.107	.3977	.714	.440	.274
102	Vastus externus muscle	48	29.83	4.65	25.18	3.49	3.96	2.07	1.89	.109	.3768	.696	.461	.235
103	Semitendinosus muscle	48	32.06	4.82	27.24	3.54	4.49	2.48	2.01	.085	.3835	.735	.475	.260
104	Rectus femoris muscle	48	29.62	4.48	25.14	2.99	3.85	1.99	1.86	.070	.3971	.694	.483	.211

TABLE 5.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen. Total.	Nitrogen. Soluble.	Nitrogen. Coagulable.	Nitrogen. Noncoagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Nitrogen. Ammoniacal.	Phosphorus. Total.	Phosphorus. Insoluble.	Phosphorus. Soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
		Hours.												
100	Semimembranosus muscle	48	100.00	28.53	15.37	13.16	0.814	2.57	0.244	100.00	20.19	79.81	51.73	28.08
101	Biceps femoris muscle	48	100.00	29.52	16.38	13.14	.724	2.69	.266	100.00	22.67	77.33	47.65	29.68
102	Vastus externus muscle	48	100.00	26.87	14.04	12.83	.739	2.56	.225	100.00	21.83	78.17	51.80	26.37
103	Semitendinosus muscle	48	100.00	29.62	16.36	13.26	.561	2.53	.276	100.00	20.28	79.72	51.53	28.19
104	Rectus femoris muscle	48	100.00	26.42	13.66	12.76	.480	2.73	.263	100.00	21.27	78.73	54.75	23.98

CHEMICAL CHANGES TAKING PLACE DURING ASEPTIC AUTOLYSIS OF BEEF.

Tables 6 to 11, inclusive, show the chemical changes which took place in 9 samples of the muscular tissues from a hind quarter of a steer that were incubated at 37° C. for periods ranging from 7 to 100 days.

Table 6 shows the composition of the tissue expressed in terms of percentages of the original material. On account of variations in the moisture content of the samples, due to losses by evaporation during incubation, and because of appreciable variations in the fat content of the samples, the data do not show the true extent of the changes which took place in the composition of the material during autolysis, a better comprehension of which may be obtained from Table 7, which shows the composition of the samples expressed in terms of moisture-free and fat-free material.

Moisture, fat-free basis shows a fairly regular decrease as the period of incubation increases, the sample incubated 100 days containing 72.64 per cent, as compared with 76.61 per cent in the fresh material.

Ash.—This constituent shows no regular changes, as was to have been expected.

Total nitrogen.—This constituent shows some irregular changes, but the fact that there are apparent increases as well as decreases in the nitrogen content of the incubated samples, as compared with the fresh material, indicates that the differences are without significance.

Total phosphorus.—The slight and irregular apparent changes in this constituent would seem to be due to differences in the phosphorus content of the different muscle bundles from which the samples were taken. By referring to Table 2 it may be noted that the differences in total phosphorus content of the various muscle bundles are approximately of the same size as the apparent changes in the phosphorus content of the muscles noted in Table 7. There is a peculiar regularity in these changes, however, that is hard to explain and which will be referred to later.

Other forms of phosphorus.—Inasmuch as the several samples used in this experiment differed in respect to their total phosphorus content, they must also have contained different initial amounts of one or more of the several groups of phosphorus compounds. The difference between the amount of a given form of phosphorus present in the composite sample and the amount present in an incubated sample, therefore, can not legitimately be taken to represent the exact amount by which that constituent changed during incubation. Presumably the initial ratio of a given form of phosphorus to total phosphorus is more nearly constant throughout a given carcass than is the actual percentage of the given form of phosphorus; so that in the present experiment a more nearly accurate measure of the autolytic changes would seem to be afforded by the difference between that ratio in the composite fresh sample and the corresponding ratio in the incubated sample. The changes effected by autolysis in the various forms of phosphorus will therefore be discussed in connection with Table 11, where the data are presented in the form indicated.

TABLE 6.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
									Total.	Soluble.	Insoluble
		Hours.	*Days.*								
109	Composite sample, left hind quarter	24	0	74.90	2.23	1.11	3.49	0.0087	0.206	0.164	0.042
110	Sample No. 22	24	7	74.73	2.51	1.14	3.57	.0185	.213	.190	.023
111	Sample No. 17	24	14	73.32	4.11	1.12	3.51	.0225	.207	.193	.014
112	Sample No. 11	24	21	74.13	2.48	1.19	3.62	.0254	.221	.205	.016
113	Sample No. 12	24	28	72.69	3.51	1.09	3.46	.0349	.209	.193	.016
120	Sample No. 33	24	42	72.25	3.03	1.17	3.67	.0365	.219	.207	.012
121	Sample No. 18	24	64	72.69	3.44	1.18	3.42	.0509	.208	.196	.012
122	Sample No. 32	24	77	70.62	3.90	1.20	3.74	.0476	.225	.217	.008
124	Sample No. 3	24	93	71.31	2.95	1.27	3.68	.0588	.225	.215	.010
125	Sample No. 2	24	100	70.76	2.59	1.27	4.06	.0629	.235	.231	.004

TABLE 7.—*Composition expressed in terms of percentage of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		Hours.	*Days.*							
109	Composite sample, left hind quarter	24	0	76.61	4.85	15.26	0.0382	0.899	0.718	0.181
110	Sample No. 22	24	7	76.66	5.01	15.69	.0815	.938	.836	.102
	Change	0	7	+0.05	+0.16	+0.43	+.0433	+.039	+.118	−.079
111	Sample No. 17	24	14	76.46	4.96	15.55	.0996	.918	.855	.063
	Change	0	14	−0.15	+0.11	+0.29	+.0614	+.019	+.137	−.118
112	Sample No. 11	24	21	76.02	5.09	15.48	.1084	.947	.877	.070
	Change	0	21	−0.59	+0.24	+0.22	+.0702	+.048	+.159	−.111
113	Sample No. 12	24	28	75.33	4.58	14.54	.1464	.878	.811	.067
	Change	0	28	−1.28	−0.27	−0.72	+.1082	−.021	+.093	−.114
120	Sample No. 33	24	42	74.52	4.73	14.85	.1478	.885	.835	.050
	Change	0	42	−2.09	−0.12	−0.41	+.1096	−.014	+.117	−.131
121	Sample No. 18	24	64	75.28	4.94	14.33	.2134	.872	.823	.049
	Change	0	64	−1.33	+0.09	−0.93	+.1752	−.027	+.105	−.132
122	Sample No. 32	24	77	73.48	4.71	14.68	.1868	.884	.850	.034
	Change	0	77	−3.12	−0.14	−0.58	+.1486	−.015	+.132	−.147
124	Sample No. 3	24	93	73.49	4.93	14.30	.2284	.875	.835	.040
	Change	0	93	−3.13	+0.08	−0.96	+.1902	−.024	+.117	−.141
125	Sample No. 2	24	100	72.64	4.76	15.23	.2362	.882	.867	.015
	Change	0	100	−3.97	−0.09	−0.03	+.1980	−.017	+.149	−.166

Table 8 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the original material; but the changes in the composition of the extract are shown more clearly in Table 9, where the results are calculated in terms of percentages of the moisture-free and fat-free material. Table 9 shows the composition of the 0.9 per cent sodium chlorid extract of the samples expressed in terms of moisture-free and fat-free material.

Total solids.—The data for total solids show some striking peculiarities. The samples incubated for 7, 14, and 21 days show decreases amounting to 4.54, 2.89, and 3.75 per cent, respectively, while the samples incubated for periods ranging from 28 to 100 days show fairly regular increases varying from 3.62 to 8.77 per cent. The probable reasons for these irregular changes in total solids will be discussed in connection with soluble nitrogen, Table 10.

Ash of extract.—There is a fairly marked increase in this constituent in the incubated samples as compared with the fresh material, but the extent of the increase bears no relation to the length of the incubation period. In the column headed "Total soluble phosphorus" increases may be noted in that constituent that go to confirm and explain the increases in ash of extract. The increase in ash of extract is apparently due, in large part at least, to the change of insoluble phosphorus compounds (probably organic) to soluble forms. The cause and nature of these changes will be discussed in connection with changes taking place in the phosphorus compounds.

Organic extractives were determined by subtracting the percentage of ash from that of total solids. The same general changes may be noted in this constituent as have previously been noted in case of total solids.

Acidity.—The samples incubated for 7, 14, and 21 days, respectively, show practically no changes in acidity; while the samples incubated for longer periods show quite marked increases, ranging from 1.18 per cent in case of the sample incubated 42 days to 1.87 per cent in case of the sample incubated 77 days. It is of interest to note that the marked increases in acidity that took place in the samples incubated for periods ranging from 28 to 100 days are accompanied by rather marked increases in organic extractives and total soluble nitrogen, which would indicate that the acid-forming and the proteolytic enzyms were most active at the same time. The presence of autolytic acid-forming enzyms in various body tissues is well known. (See Inouye, 1908, and Vernon, 1910.) Such enzyms produce both volatile and nonvolatile acids, among which are lactic, succinic, formic, acetic, and butyric. The action of lactic acid producing enzyms appears to have been studied most extensively.

Total soluble nitrogen.—This constituent exhibits changes similar to those previously noted in case of total solids and organic extractives. The sample incubated for 7 days shows a marked decrease in soluble nitrogen that amounts to 0.895 per cent; samples incubated for 14 and 21 days show gradually reduced decreases; while samples incubated for periods ranging from 28 to 100 days show gradual increases in this constituent. It is of interest to note that the decrease in soluble nitrogen in the case of the sample incubated 7 days, which amounts to 0.895 per cent, is nearly as great as the increase in soluble nitrogen in the case of the sample incubated 100 days, which amounts to 1.005 per cent. It is apparent that there was at first a rapid decrease in soluble nitrogen, as noted in case of the sample incubated 7 days, while subsequently the change was in the other direction, although in the case of the samples incubated 14 and 21 days the reversal in direction is apparent only when the results are compared with those from the sample incubated 7 days.

The probable causes of these changes will be discussed in connection with the nitrogen data in Table 10.

Coagulable nitrogen.—There is a marked decrease in the coagulable nitrogen of the samples as the period of incubation increases. The fresh material contains 2.715 per cent coagulable nitrogen, while the sample incubated 100 days contains only 0.536 per cent, so that the decrease amounts to 2.179 per cent. The causes of these changes will be discussed in connection with Table 10.

Noncoagulable nitrogen.—The data for noncoagulable nitrogen show a fairly regular increase in this constituent throughout the course of the experiment, but the rate of increase varies considerably

TABLE 8.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Total solids.	Ash.	Organic extractives.	Acid, as lactic.	Nitrogen. Total soluble.	Nitrogen. Coagulable.	Nitrogen. Noncoagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Phosphorus. Total soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
		Hours.	*Days.*												
109	Composite sample, left hind quarter	24	0	7.39	1.02	6.37	0.72	1.04	0.621	0.419	0.015	0.0782	0.164	0.115	0.049
110	Sample No. 22	24	7	6.32	1.17	5.15	.69	.831	.356	.475	.045	.1412	.190	.182	.008
111	Sample No. 17	24	14	6.64	1.30	5.34	.71	.903	.304	.599	.065	.1931	.193	.180	.013
112	Sample No. 11	24	21	6.68	1.29	5.39	.74	.950	.313	.637	.057	.2101	.205	.192	.013
113	Sample No. 12	24	28	8.99	1.26	7.73	1.13	1.14	.195	.945	.071	.4232	.193	.177	.016
120	Sample No. 33	24	42	8.88	1.18	7.70	1.07	1.17	.217	.953	.057	.4641	.207	.191	.016
121	Sample No. 18	24	64	8.90	1.38	7.52	1.08	1.10	.135	.965	.076	.4715	.196	.184	.012
122	Sample No. 32	24	77	9.84	1.33	8.51	1.28	1.31	.163	1.147	.067	.6100	.217	.203	.014
124	Sample No. 3	24	93	9.90	1.33	8.57	1.22	1.33	.131	1.199	.067	.6208	.215	.205	.010
125	Sample No. 2	24	100	10.95	1.39	9.56	1.27	1.48	.143	1.337	.067	.7658	.231	.217	.014

with the samples incubated for different periods of time. The maximum increase in noncoagulable nitrogen, which occurred in the sample incubated for 100 days, amounts to 3.184 per cent, while the corresponding increases in total soluble nitrogen amount to only 1.005 per cent, so that the transformation of insoluble muscle protein into soluble forms was only about one-third as great as the change of soluble coagulable protein into noncoagulable forms.

Proteose nitrogen.—There is a comparatively small amount of proteose nitrogen present in any of the samples. The most rapid increase in this constituent took place in the sample incubated 7 days, while the sample incubated 64 days shows the greatest increase. The sample incubated 100 days contains less proteose nitrogen than that incubated 7 days.

Amino nitrogen.—The changes in amino nitrogen will be discussed in connection with Table 10, where they are shown more clearly.

Phosphorus compounds. — The changes in the soluble phosphorus compounds will be discussed in connection with Table 11, for reasons that have already been indicated.

Table 10 shows the distribution of nitrogen and phosphorus compounds in the various samples referred to 100 parts of each constituent in the fresh material.

Total nitrogen.—As has been previously noted, there are some slight and irregular changes in this constituent, which are apparently without significance.

TABLE 9.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Total solids.	Ash.	Organic extractives.	Acid, as lactic.	Nitrogen.					Phosphorus.		
								Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		Hours.	*Days.*												
109	Composite sample, left hind quarter	24	0	32.31	4.46	27.85	3.15	4.547	2.715	1.832	0.066	0.342	0.718	0.503	0.215
110	Sample No. 22	24	7	27.77	5.14	22.63	3.03	3.652	1.564	2.088	.198	.620	.836	.802	.034
	Change	0	7	−4.54	+ .68	−5.22	− .12	−.895	−1.151	+ .256	+.132	+ .278	+.118	+.299	−.181
111	Sample No. 17	24	14	29.42	5.76	23.66	3.15	4.001	1.347	2.654	.288	.856	.855	.798	.057
	Change	0	14	−2.89	+1.30	−4.19	.00	−.546	−1.368	+ .822	+.222	+ .514	+.137	+.295	−.158
112	Sample No. 11	24	21	28.56	5.52	23.04	3.16	4.062	1.338	2.724	.244	.898	.877	.823	.054
	Change	0	21	−3.75	+1.08	−4.81	+ .01	−.485	−1.377	+ .892	+.178	+ .556	+.159	+.320	−.161
113	Sample No. 12	24	28	37.77	5.29	32.48	4.75	4.789	.819	3.970	.298	1.778	.811	.745	.066
	Change	0	28	+5.46	+0.83	+4.63	+1.60	+.242	−1.896	+2.138	+.232	+1.436	+.093	+.242	−.149
120	Sample No. 33	24	42	35.93	4.77	31.16	4.33	4.734	.878	3.856	.231	1.878	.835	.774	.061
	Change	0	42	+3.62	+ .31	+3.31	+1.18	+.187	−1.837	+2.024	+.165	+1.536	+.117	+.271	−.154
121	Sample No. 18	24	64	37.29	5.78	31.51	4.53	4.609	.566	4.043	.318	1.976	.823	.772	.051
	Change	0	64	+4.98	+1.32	+3.66	+1.38	+.062	−2.149	+2.211	+.252	+1.634	+.105	+.269	−.164
122	Sample No. 32	24	77	38.63	5.22	33.41	5.02	5.142	.640	4.502	.263	2.395	.850	.798	.052
	Change	0	77	+6.32	+ .76	+5.56	+1.87	+.595	−2.075	+2.670	+.197	+2.053	+.132	+.295	−.163
124	Sample No. 3	24	93	38.47	5.17	33.30	4.74	5.168	.509	4.659	.260	2.412	.836	.796	.040
	Change	0	93	+6.16	+ .71	+5.45	+1.59	+.621	−2.206	+2.827	+1.94	+2.070	+.118	+.293	−.175
125	Sample No. 2	24	100	41.08	5.21	35.87	4.76	5.552	.536	5.016	.251	2.873	.867	.816	.051
	Change	0	100	+8.77	+ .75	+8.02	+1.61	+1.005	−2.179	+3.184	+.185	+2.531	+.149	+.313	−.164

Soluble nitrogen.—The data under this heading simply show more clearly changes that have been previously discussed in connection with Table 9. There are at first marked decreases in the soluble nitrogen in the samples incubated for 7, 14, and 21 days, after which there are gradual increases in this constituent as the incubation period progresses. The total increase in the sample incubated 100 days amounts to 22.12 per cent of the soluble nitrogen present in the fresh sample. This increase is practically the same as the decrease in soluble nitrogen in the sample incubated 7 days.

The increase in soluble nitrogen in the incubated samples is clearly due to the action of a proteolytic endoenzym, capable of attacking native proteins and of working in an acid medium. The presence of such an enzym in muscular tissues, as well as in other body tissues, is generally recognized. Vernon (1910) names such an enzym "protease." A discussion of the factors limiting the total extent of the action of this enzym upon the insoluble muscle proteins is hardly within the province of this paper.

The decrease in soluble nitrogen in case of the samples incubated for 7, 14, and 21 days is harder to explain. The following appears to be the most reasonable explanation of this condition. It is a well-known fact that muscular tissue contains a much higher proportion of soluble protein before rigor mortis has set in than after that process is complete. Oppenheimer (1909) cites experiments where 87.3 per cent of the total protein of muscular tissue was found in soluble condition before rigor mortis had set in, while only 28.5 was present in the soluble form after rigor was complete. In our experiments the fresh material was analyzed 24 hours after slaughter of the animal, at which time rigor mortis was assumed to be complete. The fact that the samples incubated for 7, 14, and 21 days show decreases in total soluble nitrogen as compared with the fresh material, indicates very clearly that rigor mortis was not complete when the fresh muscular tissue was analyzed. It may be noted that while the samples incubated for 7, 14, and 21 days show decreases in total soluble nitrogen, as compared with the fresh material, the maximum decrease was reached in case of the sample incubated 7 days, and from that time on the change was in the other direction. This fact indicates that the coagulation of muscle proteins, which accompanies rigor mortis, was complete at the end of 7 days and probably at an earlier date.

Coagulable nitrogen.—There is a marked decrease in this constituent during the course of the experiment, the decrease being most rapid during the first 7 days. The sample incubated for 100 days contains only 19.76 per cent of the amount of coagulable protein in the fresh sample. However, these figures do not show the full extent of the transformation of coagulable protein into noncoagulable forms, since there is a gradual increase in the total soluble protein during the experiment (except in the case of the samples incubated 7, 14, and 21 days), whereas the comparisons are based upon the amount of coagulable protein present in the fresh material. The data under the heading "Noncoagulable nitrogen" show more clearly the true extent of the transformation of coagulable protein into noncoagulable forms.

The change of coagulable protein into noncoagulable forms may be ascribed to the action of the enzym protease, which also acts upon the insoluble muscle proteins.

Noncoagulable nitrogen.—There is a practically continuous increase in the noncoagulable nitrogen throughout the course of the experiment; the entire increase amounting to 173.82 per cent, as compared with a decrease of 80.24 per cent in the coagulable nitrogen during the same period.

Proteose nitrogen.—The most rapid increase in this constituent occurs during the first seven days of the experiment, though there are some greater increases after that time. The sample incubated for 100 days contains only slightly more proteose nitrogen than the sample incubated for 7 days, and not as much as several of the samples incubated for intermediate periods. These data indicate, in conformity with the well-known fact that proteoses are simply intermediate products in the autolysis of muscle proteins, that there is no appreciable accumulation of proteose nitrogen during autolysis. It is very apparent that the amount of proteoses in muscular tissue is not a true measure of protein autolysis.

In the light of present information, proteoses may be regarded as a product of the action of the enzym protease upon muscle proteins.

Amino nitrogen.—The changes in amino nitrogen effected by the autolysis are very interesting in that each change is in the nature of a pronounced increase, and that each successive increase is larger than its predecessor, until, in the sample that was incubated for 100 days, the amount of amino nitrogen is more than eight times as large as that in the nonincubated sample. In a general way, the rate of increase diminishes as the incubation period is lengthened, since more than one-half of the total increase occurs during the first 28 days of autolysis.

The increases in amino nitrogen represent an accumulation of the end products of proteolysis, and furnish an excellent index of the extent of protein autolysis. They are produced by the combined action of various proteolytic enzyms—protease and erepsin in particular—upon the muscle proteins and their cleavage products.

Ammoniacal nitrogen.—The data show an almost continuous increase in this constituent during the entire experiment. In general, the increases in ammoniacal nitrogen follow those in amino nitrogen,

TABLE 10.—*Distribution of nitrogen and phosphorus on basis of 100 parts of respective constituents at beginning of incubation period.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Nitrogen.							Phosphorus.				
				Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	In-soluble.	Soluble.	Soluble inorganic.	Soluble organic.
		Hours.	*Days.*												
109	Composite sample, left hind quarter	24	0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
110	Sample No. 22	24	7	102.81	80.31	57.62	113.94	301.53	181.40	213.41	104.26	56.12	116.40	159.30	15.88
111	Sample No. 17	24	14	101.92	87.99	49.61	144.87	439.13	250.21	260.89	102.04	34.56	119.06	158.54	26.54
112	Sample No. 11	24	21	101.45	89.34	49.30	148.70	371.65	262.63	283.99	105.29	38.48	122.14	163.57	25.05
113	Sample No. 12	24	28	95.27	105.33	30.17	216.73	454.84	519.91	383.63	97.63	36.78	112.98	147.93	31.05
120	Sample No. 33	24	42	97.33	104.12	32.34	210.52	351.71	549.07	387.22	98.41	27.45	116.32	153.72	28.68
121	Sample No. 18	24	64	93.91	101.36	20.83	220.73	485.57	577.69	559.08	96.99	27.42	114.54	153.38	23.51
122	Sample No. 32	24	77	96.22	113.10	23.57	245.79	401.06	700.15	489.31	98.25	18.52	118.38	158.50	24.35
124	Sample No. 3	24	93	93.71	113.66	18.75	254.33	395.98	705.32	598.30	97.31	21.86	116.33	158.11	18.44
125	Sample No. 2	24	100	99.83	122.12	19.76	273.82	383.29	840.09	618.73	98.10	8.55	120.69	162.12	23.60

though they seem to be more nearly in conformity with a regular rule. On the whole, the rate of ammonia production decreases as the ammonia accumulates; yet in view of the small amounts in which this constituent is present (see Table 9), it would seem that the ammonia is but an index of the retarding agent and not the retarding agent itself.

The production of ammonia is clearly due to enzym action, but the nature of the specific enzym and of the mother substance remains to be determined.

Table 11 shows the distribution of nitrogen and phosphorus expressed in terms of percentages of total nitrogen and total phosphorus.

Soluble nitrogen constitutes 29.8 per cent of the total nitrogen in the fresh material, 23.28 per cent in the material incubated for 7 days, and 36.45 per cent in the sample incubated for 100 days. The decrease in the ratio of soluble nitrogen to total nitrogen in the samples incubated for 7, 14, and 21 days confirms similar data presented in Table 10.

Coagulable nitrogen makes up 17.79 per cent of the total nitrogen in the fresh material and only 3.52 per cent in the sample incubated 100 days. More than 80 per cent of the coagulable nitrogen present in the fresh material has been converted into noncoagulable forms.

Proteose nitrogen constitutes a relatively small proportion of the total nitrogen both in the fresh and in the incubated material.

TABLE 11.—*Distribution of nitrogen and phosphorus, expressed in terms of percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Incubation period.	Nitrogen. Total.	Nitrogen. Soluble.	Nitrogen. Coagulable.	Nitrogen. Noncoagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Nitrogen. Ammoniacal.	Phosphorus. Total.	Phosphorus. Insoluble.	Phosphorus. Soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
		Hours.	*Days.*												
109	Composite sample, left hind quarter	24	0	100.00	29.80	17.79	12.01	0.43	2.24	0.25	100.00	20.16	79.84	55.97	23.87
110	Sample No. 22	24	7	100.00	23.28	9.97	13.31	1.26	3.95	.52	100.00	10.85	89.15	85.51	3.64
	Change	0	7	0.00	−21.89	−43.96	+ 10.83	+193.28	+ 76.4	+107.6	0.00	−46.18	+11.66	+52.78	−84.75
111	Sample No. 17	24	14	100.00	25.73	8.66	17.07	1.85	5.50	.64	100.00	6.83	93.17	86.96	6.21
	Change	0	14	0.00	−13.67	−51.33	+ 42.16	+330.86	+ 145.5	+156.0	0.00	−66.13	+16.70	+55.37	−73.98
112	Sample No. 11	24	21	100.00	26.24	8.65	17.59	1.57	5.80	.70	100.00	7.37	92.63	86.95	5.68
	Change	0	21	0.00	−11.93	−51.41	+ 46.58	+266.35	+158.9	+179.9	0.00	−63.46	+16.02	+55.35	−76.21
113	Sample No. 12	24	28	100.00	32.95	5.64	27.31	2.05	12.23	1.01	100.00	7.59	92.41	84.81	7.60
	Change	0	28	0.00	+10.57	−68.33	+127.50	+377.4	+445.7	+302.7	0.00	−62.33	+15.73	+51.53	−68.20
120	Sample No. 33	24	42	100.00	31.88	5.91	25.97	1.55	12.65	1.00	100.00	5.62	94.38	87.42	6.96
	Change	0	42	0.00	+ 6.98	−66.77	+116.30	+261.4	+464.1	+297.8	0.00	−72.10	+18.20	+56.19	−70.84
121	Sample No. 18	24	64	100.00	32.16	3.95	28.21	2.22	13.79	1.49	100.00	5.70	94.30	88.51	5.79
	Change	0	64	0.00	+ 7.93	−77.82	+135.04	+417.0	+515.1	+495.3	0.00	−71.74	+18.11	+58.14	−75.74
122	Sample No. 32	24	77	110.00	35.03	4.36	30.67	1.79	16.31	1.27	100.00	3.80	96.20	90.29	5.91
	Change	0	77	0.00	+17.54	−75.51	+155.49	+316.8	+627.6	+408.5	0.00	−81.16	+20.49	+61.32	−75.24
124	Sample No. 3	24	93	100.00	36.14	3.56	32.58	1.82	16.87	1.60	100.00	4.53	95.47	90.95	4.52
	Change	0	93	0.00	+21.28	−79.99	+171.40	+323.6	+652.6	+538.3	0.00	−77.53	+19.58	+62.50	−81.06
125	Sample No. 2	24	100	100.00	36.45	3.52	32.93	1.65	18.86	1.55	100.00	1.76	98.24	92.50	5.74
	Change	0	100	0.00	+22.33	−80.21	+174.31	+284.0	+741.5	+519.7	0.00	−91.29	+23.05	+65.27	−75.95

Amino nitrogen.—In the course of 100 days of autolysis the amino nitrogen has increased from 2.24 per cent to 18.86 per cent of the total nitrogen, or from less than one-tenth to more than one-half of the total soluble nitrogen.

Insoluble phosphorus.—The ratio of insoluble phosphorus to total phosphorus is seen to be a decreasing function of the time of incubation, and while the rate of decrease is not entirely regular it will be seen that, on the whole, the rate diminishes as the incubation period is extended. At the end of the one-hundredth day of incubation but 1.76 per cent of the total phosphorus remains in insoluble form, as against 20.16 per cent originally present. These changes may be considered as due to the action of the enzyms lipase and nuclease upon the phosphatids and nucleic acids, respectively.

Total soluble phosphorus.—The changes in the ratio of total soluble phosphorus to total phosphorus are naturally equal and opposite to corresponding changes in the ratio of insoluble phosphorus to total phosphorus, and have no further significance.

Soluble organic phosphorus.—The figures for the ratio of soluble organic phosphorus to total phosphorus are peculiar, in that during the first seven days of autolysis this ratio decreased from its initial value of 23.87 per cent to its minimum value of 3.64 per cent. This large initial decrease, however, should not be regarded with suspicion, since the continued increase in soluble inorganic phosphorus indicates the continued cleavage of organic phosphorus that one would expect. It would appear, therefore, that after the first energetic cleavage of the preformed soluble organic phosphorus compounds, the activity of the phosphatase decreases, and that new soluble organic compounds of phosphorus—cleavage products from the insoluble fraction—accumulate at a rate that is sometimes greater than the rate at which they are broken down by the phosphatase. The possibility, of course, is not excluded that the accumulating phosphorus compounds are inherently less susceptible to the action of the phosphatase than are those originally present in the fresh meat.

Soluble inorganic phosphorus.—Except in the case of samples Nos. 112 and 113, the ratio of soluble inorganic phosphorus to total phosphorus increases continuously throughout the experiment, until at the end of the one-hundredth day of autolysis it has attained a value of 92.50 per cent, as against its original value of 55.97 per cent—more than three-fourths of the increase having taken place during the first seven days of incubation.

SUMMARY OF RESULTS OF AUTOLYSIS EXPERIMENTS.

The results of the autolysis experiments reported in this paper may be summarized as follows:

1. Physical changes in the samples of muscular tissue were not marked, even at the conclusion of the experiment, and consisted

chiefly of a slight softening of the tissues, an exudation of meat juices, and a change in color of the meat.

2. Incubated samples developed a characteristic, rather pleasant odor, similar to that of rare roast beef, the odor becoming more pronounced as the period of incubation progressed.

A sample which had been incubated 103 days did not prove to be a palatable food for human consumption.

3. Total soluble extract or total solids showed a decrease early in the experiment, and later an increase, the total increase amounting to 8.77 per cent of the amount present in the fresh material.

4. Ash of extract showed appreciable, but not regular, increases, which correspond roughly with similar increases in total soluble phosphorus.

5. The acidity of the samples showed appreciable increases, particularly toward the close of the experiment.

6. The changes which took place in the nitrogenous compounds consisted, in general, in an increase in total soluble nitrogen and in a conversion of the higher forms of soluble nitrogenous compounds into simpler combinations.

(*a*) Coagulable nitrogen showed a marked decrease, more than 50 per cent of which took place during the first week of the experiment. The total decrease amounted to approximately 80 per cent of the amount present in the fresh material.

(*b*) Noncoagulable nitrogen increased fairly regularly during the course of the experiment, the total increase amounting to 173.8 per cent.

(*c*) Proteose nitrogen increased rapidly early in the experiment, and the quantity then remained practically stationary during the remainder of the incubation period.

(*d*) Amino nitrogen showed greater actual and relative changes than any other nitrogenous constituent. This result was to have been expected, since this constituent represents, in a large degree, an accumulation of the end-products of proteolysis. The total increase in amino nitrogen amounted to 740 per cent, and nearly one-fifth of the total nitrogen was in the amino form at the end of the experiment.

(*e*) Ammoniacal nitrogen showed marked and fairly regular increases, the total increase amounting to over 500 per cent, although this constituent made up only 1.55 per cent of the total nitrogen at the close of the experiment.

7. Phosphorus compounds showed changes which consisted chiefly in appreciable increases in total soluble phosphorus and in soluble inorganic phosphorus, and in corresponding decreases in insoluble and in soluble organic phosphorus.

(*a*) Insoluble phosphorus decreased rapidly early in the experiment and more slowly and fairly regularly during the remainder of the period, the total decrease amounting to 91.29 per cent of the amount present in the fresh material as calculated from the ratios of insoluble to total phosphorus.

(*b*) Total soluble phosphorus showed increases corresponding to the decreases in insoluble phosphorus, the total increase amounting to 23.05 per cent, as calculated from the ratios of total soluble phosphorus to total phosphorus.

(*c*) Soluble inorganic phosphorus increased rapidly early in the experiment, and more slowly toward the close, the total increase amounting to 65.27 per cent, as calculated from the distribution figures.

(*d*) Soluble organic phosphorus showed decreases corresponding to the increases in soluble inorganic phosphorus, the total decrease amounting to 75.95 per cent, as calculated from the organic phosphoric ratios.

8. There was no development of free hydrogen sulphid during the course of the experiment.

COLD-STORAGE EXPERIMENTS WITH FRESH BEEF.

PROCEDURE.

The work undertaken in this investigation naturally groups itself under two headings, viz, (1) Bacteriological and histological studies, and (2) chemical and physical studies. The bacteriological and histological investigations were conducted by Doctor McBryde, and the chemical and physical investigations by Mr. Hoagland and Mr. Powick. Organoleptic observations were carried on jointly.

The following general plans were observed in carrying on the work, and such additional details as seem pertinent will be mentioned in connection with the individual experiments.

High-grade fat steers were purchased as needed at a local stockyard and were slaughtered in the usual manner under the supervision of one of the writers in a local modern packing house, and were held there under refrigeration until chilled, usually for 48 hours. The two hind quarters were then cut from the carcass, carefully wrapped in cheesecloth and paper, and transported by motor truck to the cold-storage rooms of the Biochemic Division at the Bureau of Animal Industry. The trip usually required about one hour. The rooms referred to were as follows:

Room No. 1: 6 by 9 feet by 7 feet 6 inches high, with overhead bunker, closed brine-coil system of refrigeration, and automatic temperature control. Overhead rails were provided for hanging the meat. This room was used for storing the beef described in all of the following experiments except one, in which the beef was stored in the cooler of a local packing house.

Room No. 2: 6 by 6 feet by 7 feet 4 inches high, with overhead bunker, closed brine-coil system of refrigeration, forced circulation of air, and automatic temperature control. This room was used as a place in which to cut up the meat and prepare it for analysis, and for certain laboratory work which required a low temperature.

As soon as the beef was received from the packing house it was placed in cold-storage room No. 1, unwrapped, weighed, and hung up. During each storage experiment the temperature of the room was recorded continuously by means of a recording thermometer. It was the aim to keep the temperature at 32° to 36° F., but the exact temperature range will be stated in connection with each experiment. The humidity of the room was determined once each week by means of a sling hygrometer, and observations as to the condition of the meat were made at the same time. Each quarter of beef was weighed at the end of the period of storage.

BACTERIOLOGICAL AND HISTOLOGICAL STUDIES.

In the bacteriological study of the carcasses the two main questions investigated were: (1) Whether bacteria are present in the muscular tissues of beef animals which have been passed as normal after careful ante-mortem and post-mortem examination, and (2) whether the bacteria and molds which grow on the surfaces of cold-stored meats penetrate the meats to any marked degree during varying periods of storage.

With regard to the second question, there are two methods by which the surface bacteria might penetrate the meats, namely, (1) by direct growth or extension into the muscular tissues or (2) by growth along the tendinous sheaths or connective-tissue elements between the muscle groups. In the present study the latter method was not investigated and the cultures were always made from the muscular tissue, avoiding the connective-tissue elements, the idea being to determine whether the bacteria actually penetrate the muscular tissue.

In examining the quarters bacteriologically the following procedure was adopted: A slice or section from 3 to 4 inches thick was cut from the upper portion of the round. From this slice a rectangular block extending from the outer surface to the bone was cut, as indicated by the dotted line in the diagram (fig. 1). This block, which measured about 4½ by 8 inches and weighed from 6 to 8 pounds, was first immersed in actively boiling water for three minutes, next in bichlorid solution (0.5 per cent) for five minutes, and was then wrapped in sterile gauze which had been wrung out in the bichlorid solution. This was done in order to sterilize the surface of the meat and to prevent the growth and possible penetration of bacteria from the outside, pending the taking of cultures.

It was not always possible to make cultures immediately, but they were always made within two hours; and during this time the block of meat was kept wrapped in the bichlorid gauze and at cold-storage temperature (34°–36° F.).

The short immersion in the boiling water served to coagulate the muscle protein to the depth of from 3 to 5 mm., but did not cause sufficient elevation of the inside temperature to have any injurious effect on the bacteria present. A test was made by introducing a thermometer into a block of meat of the size described above so that the bulb rested at the center of the meat mass, and there was no appreciable rise in temperature during the three minutes' interval in the hot water. The outer zone of coagulated protein served to prevent the penetration of the bichlorid solution into the meat.

Beginning about 1 inch from the outer surface a series of cultures were taken at intervals of an inch, proceeding from the outside toward the bone, and these cultures were numbered as indicated in the diagram. In taking the cultures a series of sterile scalpels were used, one being used to cut through the outer or surface portion, and others to make deeper cuts in order not to carry in any of the bichlorid solution adhering to the surface of the meat. Plugs of meat about a centimeter square were used in making the cultures. Cultures were made in neutral beef broth and in glucose agar from which the air had been expelled by boiling. When clouding occurred in the bouillon cultures, agar plates were poured and the organisms present were plated out.

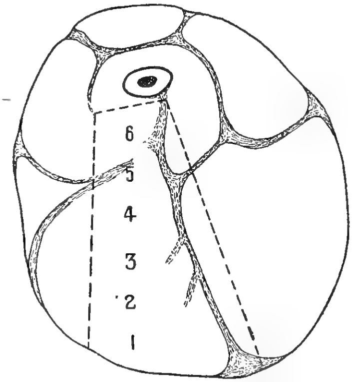

FIG. 1.—Diagram of a cross section of a beef round, showing points at which cultures were taken.

In 4 of the 7 carcasses studied, a small micrococcus was found. This organism was not generally distributed throughout the muscular tissue of any one quarter, but was encountered here and there. The fact that is was usually found at some distance below the outer surface, together with the fact that it was found in the fresh or chilled quarters as well as in the stored quarters, would indicate that it was present in the carcass at the time of slaughter. In three of the cold-stored carcasses, those held for 28, 54, and 63 days, it was encountered here and there and was not generally distributed through the muscular tissues, which would indicate that there had been no multiplication of the organism during the storage of these quarters. In the quarter which was held in storage for the longest period of time (i. e., 177 days) the micrococcus was found to be more generally distributed than in the other quarters. This was probably due to irregularities in the storage temperature during this experiment, the temperature rising sufficiently high at times to permit of multiplication of the organism.

The micrococcus encountered in the carcasses was tested on laboratory animals and was found to possess no pathogenic properties. The absence of pathogenicity is further borne out by the fact that steaks cut from all of the quarters were eaten by the investigators without any ill effects.

In addition to the micrococcus described above, a small Gram-positive bacillus was noted in one of the fresh (i. e., chilled) quarters. This organism grew chiefly along the line of stab, but was not a strict anaerobe. It also was of no pathogenic significance.

Histological studies were made by taking bits of muscular tissues at points about 2 inches below the outer surfaces of the rounds. The tissues were hardened in alcohol, embedded in celloidin, and sectioned. The sections were stained with hematoxylin and eosin and examined as to histological structure.

CONCLUSIONS FROM BACTERIOLOGICAL AND HISTOLOGICAL STUDIES.

The following conclusions would seem warranted: (1) Certain bacteria (chiefly micrococci) may be normally present in the carcasses of healthy animals slaughtered for beef; (2) these bacteria possess no pathological significance and do not appear to multiply in the cold-stored carcasses, provided the cold-storage room is maintained at the proper temperature; (3) bacteria and molds grow on the surface of cold-storage carcasses, but do not penetrate to any great depth (less than 1 inch in 177 days); (4) bacteria apparently are not concerned in the changes leading to increased tenderness in cold-stored meats; (5) microscopic sections failed to show any noticeable histological changes in the muscular tissue after 77 days of storage.

CHEMICAL AND PHYSICAL STUDIES.

PREPARATION OF MATERIAL.

Shortly after the beef had been received from the packing house one of the quarters was transferred to cold-storage room No. 2 and was there cut up into several parts, viz, round, loin, rump, and flank, which were then prepared for analysis.

Round.—Two cross sections, each about 2.5 inches thick, were cut from the round, one at the butt and the other at a place about half way between the butt and the hock joint. These sections were trimmed free of fat, bone, and connective tissue; the resulting lean meat was ground three times through a meat grinder; and samples were transferred to glass jars which were then tightly stoppered and stored at 34° F. until analytical work was begun.

Rump.—The entire rump was trimmed free of bone and connective tissue and as free as possible of fat, and the lean meat was then prepared for analysis as above.

Loin.—The loin was first cut into what are known as the short loin and the sirloin butt. From the first part porterhouse and club steaks are cut, while sirloin steaks are cut from the second part. Two sections, each about 2.5 to 3 inches thick, were then cut for analysis. The first section was cut from the small end of the sirloin butt, the second from the small end of the short loin. In the case of the quarters of beef that had been held in storage, the small end of the short loin was trimmed free of meat that had become dried or darkened through exposure before the section was cut for analysis.

For the purpose of testing the quality of the meat, a porterhouse steak about 2 inches thick was cut from the large end of the short loin.

Flank.—This cut was analyzed in only one experiment, because of the fact that the flank becomes so dry on long storage that it is difficult to prepare for analysis, and because it was considered that the analytical results would not be of great value.

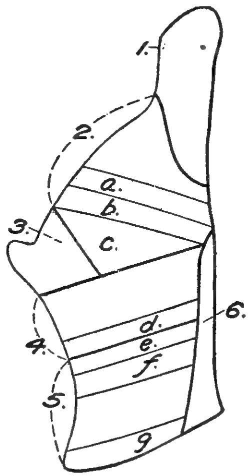

FIG. 2.—Diagram of a hind quarter of beef showing (by numbers) the usual wholesale cuts and (by letters) the sections taken for bacteriological and chemical examination.

Cuts.—(1) Shank; (2) round; (3) rump; (4, 5) loin; (4) sirloin butt; (5) short loin; (6) flank.

Sections.—(*a*, *c*) Sections for chemical examination; (*b*) section for bacteriological examination; (3) rump taken for chemical examination; (*d*, *g*) sections taken from loin for chemical examination; (*e*) test steak; (*f*) section for bacteriological examination.

Fat samples.—The following samples of fatty tissue were taken for analysis: External fat, intermuscular fat, and kidney fat.

All external fat was trimmed from each section of meat cut from the round, rump, and loin, and a sample of the combined material was taken for examination. The same practice was followed in case of the intermuscular fat. The entire kidney fat was stripped from the loin, cut up into small pieces, and reduced to a convenient quantity by quartering. This reduced quantity was ground and a sample of the ground fat was taken for examination. The sample of fatty tissue of each class was rendered in a large casserole on a steam bath and the fat was filtered and retained in bottles for analysis.

METHODS OF ANALYSIS.

Analytical work on the samples of meat was usually started approximately 15 hours after the meat had been prepared for analysis.

The methods of analysis used in these experiments were the same as those followed in studying the changes that took place in meat on autolysis, except where changes or additions are noted.

The iodin number of the fats were determined by means of the Hanus method.

Refractive indices of the fats were determned at 40° C. by means of an Abbé refractometer.

Acidity was determined by titrating a weighed quantity of the fat against standard alkali solution in the presence of hot neutral alcohol and with phenolphthalein as indicator.

Rancidity was determined by the method of Kreis, which is as follows: Shake 5 c. c. of the fat with equal volumes of a 1 per cent solution of phloroglucin in ether and of concentrated hydrochloric acid. Rancidity is detected by the development of a pink or red color, the degree of rancidity being indicated by the depth of the color.

Quality of meat.—The quality of the meat was judged in part by appearance, odor, and condition as indicated by handling, but principally by sampling portions of well-broiled porterhouse steaks, which were cut from the fresh quarter of beef at the beginning of the storage periods and from the corresponding quarter at the end of the storage periods. The steak from each quarter of beef was sampled by each of the authors and their individual opinions as to the quality of the meat were recorded. The judges are recorded as Mr. A, Mr. B, and Mr. C.

It is recognized that the interval of time between the sampling of the steaks from the first and second quarters of the same carcass may result in an inaccurate comparison of the quality of the two samples; but no better method of comparison seemed to be available.

EXPERIMENT NO. 1.

HISTORY OF CARCASS.

A "grade" Shorthorn steer, 4½ years old, of good quality and fairly well finished, was slaughtered in the usual manner; and the carcass was run into the fore cooler one hour after the animal had been killed. The warm carcass weighed 815 pounds. The carcass was held for 18 hours in the fore cooler, where a temperature ranging from 32° to 33° F. and a humidity of 93 per cent prevailed. It was then run into the main cooler, where it was held for 4½ hours longer at a temperature of 32° F. The humidity of this cooler was also 93 per cent. After a total storage period in the packing-house coolers of 22½ hours, the two hind quarters of the carcass were carefully wrapped in cheesecloth and paper and transported by motor truck to the bureau's cold-storage rooms, the trip requiring about one hour.

The packing-house coolers in which the above carcass and those used in subsequent experiments were handled may be regarded as representative of beef coolers in modern packing houses. The overhead bunker, closed brine-coil system of refrigeration was used. The coolers were supplied with abundant refrigeration and the circulation of air was very good. On arrival at the bureau laboratories the quarters of beef were at once placed in cold-storage room No. 1, which has been previously described, and were unwrapped, weighed, and hung up. On the next morning, or 43 hours after the carcass first had been placed in cold storage, the right hind quarter was taken out and prepared for analysis by methods previously described, while the left hind quarter was held in cold storage for an additional period of two weeks.

Storage.—The temperature of cold-storage room No. 1 during the two weeks' storage period of the left hind quarter of carcass No. 1 ranged from 32° to 34° F. The humidity ranged from 72 to 84 per cent of saturation. This quarter showed a shrinkage in weight of 2.15 per cent.

QUALITY OF MEAT.

Fresh quarter in storage 43 hours.—This quarter of beef would have been classed as "choice." It was well covered with fat and had a heavy deposit of kidney fat. As it was being cut up the meat appeared well marbled with fat. The lean meat was dark red in color. The judges' opinions regarding the quality of the broiled test steak cut from this quarter of beef are as follows:

Mr. A.—The tenderloin portion is quite tender, has a good flavor, and is very palatable. The loin portion is rather tough, but has a good flavor. The flank end is very tough—almost too tough to eat.

Mr. B.—The tenderloin portion is quite tender, but not as tender as that from a high-class steak. The flank portion is very tough. On the whole the meat is juicy and of good flavor, but is rather tough.

Mr. C.—The tenderloin portion is very tender, has a good flavor, and is very palatable. The loin portion is rather tough and the flavor is not as high as might be expected in this class of meat. The flank portion is rather tough.

Stored quarter in storage 15 days, 19 hours.—At the end of the storage period the quarter of beef was in very good condition. The surface of the quarter was dry and firm, and the thin outer covering of connective tissue was parchmentlike in texture. The exposed, cut, muscular surface of the round and loin were dark brown in color and firm in texture. A slight growth of mold was visible about the shank.

As the quarter was being cut up for examination the meat appeared to be in good condition, and as far as could be judged by handling it appeared to be more tender than the meat from the corresponding quarter at the beginning of the storage period. The broiled test steak possessed the following organoleptic properties in the opinion of the respective judges:

Mr. A.—The meat from all three portions of the steak is distinctly more tender than that from the corresponding portion of the steak cut from the fresh quarter of beef. The greatest improvement is noted in the flank portion. The flavor of the meat is improved.

Mr. B.—This steak is generally superior to the steak from the fresh quarter of beef; the tenderloin portion is very tender and palatable; the loin portion is nearly as tender as was the tenderloin from the steak cut from the fresh quarter, and the flavor is improved; the flank end of the steak is fairly tender.

Mr. C.—The steak as a whole is greatly superior to the one cut from the fresh quarter of beef. The flavor and tenderness of all portions of the steak are greatly improved, this change being particularly noticeable in the flank end of the steak.

CHEMICAL EXAMINATION OF CARCASS NO. 1.

Tables 12 to 18, inclusive, show the changes in composition that occurred in carcass No. 1 during the 14 days of cold storage.

Table 12 shows the composition of the carcass expressed in terms of percentages of the fresh material. These data are not of great significance in indicating changes in composition that took place in the meat during storage, since, of course, the variations in percentages of moisture and fat affect the value of the other data. These data do show, however, the actual composition of the meat at the beginning and end of the storage period. A better comprehension of the changes which took place in the composition of the meat during storage may be had from Table 13.

Table 13 shows the composition of carcass No. 1 expressed in terms of percentages of moisture-free and fat-free material. There are slight apparent increases in moisture varying from 0.34 per cent in case of the loin to 0.74 per cent in case of the round. Slight apparent gains in ash and total nitrogen are not easy to explain.

Changes in nitrogen and phosphorous compounds will be discussed in connection with Tables 17 and 18, where the changes are shown more clearly.

TABLE 12.—*Composition expressed in terms of percentages of fresh materials.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus. Total.	Phosphorus. Soluble.	Phosphorus. Insoluble.
		D. H.								
1	Round: Right hind quarter	1 19	73.06	3.64	1.06	3.37	0.0076	0.199	0.151	0.048
7	Round: Left hind quarter	15 19	74.26	3.02	1.10	3.37	.0083	.202	.155	.047
2	Rump: Right hind quarter	1 19	72.67	4.85	1.03	3.26	.0078	.182	.147	.035
8	Rump: Left hind quarter	15 19	73.28	4.79	1.04	3.24	.0079	.192	.142	.050
3	Loin: Right hind quarter	1 19	73.01	4.66	1.01	3.27	.0076	.187	.146	.041
9	Loin: Left hind quarter	15 19	72.14	6.22	1.04	3.26	.0070	.186	.141	.045

TABLE 13.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
1	Round: Right hind quarter.	1 19	75.83	4.55	14.46	0.0328	0.853	0.650	0.203
7	Round: Left hind quarter...	15 19	76.57	4.82	14.83	.0365	.888	681	.207
	Change.................	14	+ 0.74	+ .27	+ .37	+ .0037	+ .035	+ .035	+ .004
2	Rump: Right hind quarter..	1 19	76.38	4.59	14.51	.0345	.811	.655	.125
8	Rump: Left hind quarter...	15 19	76.96	4.74	14.75	.0360	.873	.646	.276
	Change.................	14	+ 0.58	+ .15	+ .24	+ .0015	+ .062	− .009	+ .071
3	Loin: Right hind quarter...	1 19	76.58	4.50	14.62	.0341	.837	.652	.185
9	Loin: Left hind quarter.....	15 19	76.92	4.80	15.06	.0323	.858	.653	.205
	Change.................	14	+ 0.34	+ .30	+ .44	− .0018	+ .021	+ .001	+ .020

Table 14 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the fresh material. On account of the effect upon the results of variations in the fat and moisture content of the meats from which these extracts were prepared, these data have been recalculated to the moisture-free and fat-free basis and are so expressed in Table 15.

Table 15 shows the composition of the 0.9 per cent sodium chlorid extracts of the meat expressed in terms of percentages of moisture-free and fat-free material.

Appreciable decreases took place in total soluble solids, ranging from 0.05 per cent in the case of the loin to 0.73 per cent in the case of the round. It will be recalled that in the autolysis experiment reported in this paper there was a distinct decrease in total solids in the early stages of the experiment.

The ash shows appreciable increases that go hand in hand with a much smaller average increase in total soluble phosphorus. Slight changes in ash of extract are not of great significance on account of the unavoidable error in correcting for the presence of relatively large amounts of sodium chlorid in the presence of small amounts of ash.

Organic extractives and acidity show appreciable decreases that are in harmony with similar changes noted in the early stages of the autolysis experiment previously reported.

Changes in nitrogen and phosphorous compounds will be discussed in connection with Tables 17 and 18.

Table 16 shows the composition of the fat at the beginning and end of the storage period.

The iodin numbers and refractive indices show practically no changes. There are appreciable increases in the acidity of the fats, ranging from 0.52 per cent in case of external fat to 0.17 per cent in case of the intermuscular fat. The increase in acidity of the in-

TABLE 14.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
								Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D.	*H.*												
1	Round: Right hind quarter	1	19	7.01	0.99	6.02	0.77	0.980	0.528	0.452	0.030	....	0.151	0.093	0.058
7	Round: Left hind quarter	15	19	6.67	.99	5.68	.70	.922	.456	.466	.037	....	.155	.112	.043
2	Rump: Round hind quarter	1	19	6.78	.92	5.86	8.74	.946	.518	.428	.034	....	.147	.090	.057
8	Rump: Left hind quarter	15	19	6.52	.98	5.54	.68	.874	.471	.403	.033	....	.142	.110	.032
3	Loin: Right hind quarter	1	19	6.81	.94	5.87	.71	.973	.538	.435	.026	....	.146	.091	.055
9	Loin: Left hind quarter	15	19	6.39	.95	5.64	.66	.930	.503	.427	.045	....	.141	.107	.034

TABLE 15.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
								Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D.	*H.*												
1	Round: Right hind quarter	1	19	30.09	4.25	25.84	3.29	4.20	2.27	1.93	0.130	....	0.650	0.398	0.252
7	Round: Left hind quarter	15	19	29.36	4.36	25.00	3.08	4.06	2.01	2.05	.163	....	.681	.492	.189
	Change	14		−0.73	+0.11	−0.84	−0.21	−0.14	−0.26	+0.12	+.033	....	+.031	+.094	−.063
2	Rump: Right hind quarter	1	19	30.15	4.07	26.08	3.29	4.21	2.31	1.90	.150	....	.655	.402	.253
8	Rump: Left hind quarter	15	19	29.70	4.47	25.23	3.08	3.99	2.15	1.84	.151	....	.646	.501	.145
	Change	14		−0.45	+0.40	−0.85	−0.21	−0.22	−0.16	−0.06	+.001	....	−.009	+.099	−.108
3	Loin: Right hind quarter	1	19	30.50	4.19	26.31	3.18	4.36	2.41	1.95	.117	....	.652	.409	.243
9	Loin: Left hind quarter	15	19	30.45	4.37	26.08	3.05	4.30	2.33	1.97	.206	....	.653	.495	.158
	Change	14		−0.05	+0.18	−0.23	−0.13	−0.06	−0.08	+0.02	+.089	....	+.001	+.086	−.085

termuscular fat may be regarded as due to the action of the enzym lipase, while the greater increases in acidity noted in case of the external and kidney fats must be regarded as due to the combined action of the enzym lipase and of bacteria.

The fats appeared to be normal in character and gave no reaction for rancidity.

TABLE 16.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40°C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. H.					
4	Kidney fat: Right hind quarter..	1 19	42.43	1.4562	0.28	Neg.....	Normal.
10	Kidney fat: Left hind quarter....	15 19	42.38	1.4562	.68	...do.....	Do.
5	Intermuscular fat: Right hind quarter.	1 19	46.86	1.4570	.22	...do.....	Do.
11	Intermuscular fat: Left hind quarter.	15 19	46.79	1.4570	.39	...do.....	Do.
6	External fat: Right hind quarter.	1 19	56.18	1.4580	.33	...do.....	Do.
12	External fat: Left hind quarter...	15 19	55.92	1.4580	.85	...do.....	Do.

Table 17 shows the distribution of nitrogen and phosphorus in the meat on the basis of 100 parts of the respective constituents in the material at the beginning of the storage period.

Slight apparent increases in total nitrogen are without significance, as has been noted previously.

Soluble nitrogen shows appreciable decreases which range from 5.23 per cent in the case of the rump to 1.38 per cent in the case of the loin. These decreases are in harmony with decreases in total solids and organic extractives, and with the decreases in soluble nitrogen previously noted in the early stages of the autolysis experiment, and they may be explained upon the same basis as the latter.

Coagulable nitrogen shows fairly marked decreases which range from 11.45 per cent in the case of the round to 3.32 per cent in the case of the loin. In part, these decreases are due to decreases in total nitrogen; but by referring to Table 15 it may be noted that the actual decreases in coagulable nitrogen are slightly larger, on the whole, than the decreases in total soluble nitrogen. These facts indicate a slight change of coagulable nitrogen into noncoagulable forms.

Noncoagulable nitrogen shows slight increases on the whole.

Proteose nitrogen shows relatively marked increases. However, it may be noted by referring to Table 15 that the actual amount of this constituent present is comparatively small.

Ammoniacal nitrogen appears to have increased in the round and in the rump, but to have decreased in the loin. As the total increase is somewhat greater than the decrease, the general tendency would seem to be toward an increase in this constituent.

TABLE 17.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
1	Round: Right hind quarter	1 19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
7	Round: Left hind quarter	15 19	102.56	96.67	88.55	106.22	125.38	....	111.28	104.10	102.17	104.71	123.56	74.91
2	Rump: Right hind quarter	1 19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
8	Rump: Left hind quarter	15 19	101.65	94.77	93.07	96.84	100.67	....	104.35	107.69	145.36	98.70	124.56	57.59
3	Loin: Right hind quarter	1 19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
9	Loin: Left hind quarter	15 19	103.01	98.62	96.68	101.03	176.07	....	94.72	102.55	111.17	100.11	121.04	64.83

TABLE 18.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
1	Round: Right hind quarter	1 19	100.00	29.05	15.70	13.35	0.90	....	0.23	100.00	23.78	76.22	46.69	29.53
7	Round: Left hind quarter	15 19	100.00	27.38	13.55	13.83	1.10	....	.25	100.00	23.33	76.67	55.41	21.26
	Change	14 00	0.00	−5.74	−13.70	+3.57	+22.22	....	+8.55	0.00	− 1.89	+0.59	+18.68	−28.01
2	Rump: Right hind quarter	1 19	100.00	29.01	15.92	13.09	1.03	....	.24	100.00	19.26	80.74	49.56	31.18
8	Rump: Left hind quarter	15 19	100.00	27.05	14.58	12.47	1.02	....	.24	100.00	25.98	74.02	57.33	16.69
	Change	14 00	0.00	−6.76	− 8.42	−4.73	− 0.97	....	+2.75	0.00	+34.89	−8.32	+15.68	−46.47
3	Loin: Right hind quarter	1 19	100.00	29.82	16.48	13.34	.80	....	.23	100.00	22.05	77.95	48.92	29.03
9	Loin: Left hind quarter	15 19	100.00	28.55	15.47	13.08	1.37	....	.21	100.00	23.90	76.10	57.75	18.35
	Change	14 00	0.00	−4.26	− 6.13	−1.93	+70.93	....	−8.07	0.00	+ 8.39	−2.37	+18.05	−36.79

Total phosphorus shows slight increases, the significance of which is not yet apparent.

It appears that a better comprehension of the changes in the various forms of phosphorus can be had from a consideration of Table 18.

Table 18 shows the distribution of nitrogen and phosphorous compounds expressed in terms of percentages of total nitrogen and total phosphorus. It may be noted that the percentage changes expressed in this table are not identical with those shown in Table 17. These differences are due to slightly different bases of calculation, as is indicated in the headings of the respective tables.

The nitrogen data, for the most part, are self-explanatory.

Insoluble phosphorus shows a large increase in the case of the rump and an appreciable increase in the case of the loin. The irregular nature of the changes in this constituent are of undetermined significance.

Total soluble phosphorus, of course, shows changes which are equal and opposite to the changes in insoluble phosphorus. The significance of these changes has not been established.

Soluble inorganic phosphorus shows appreciable increases which range from 15.68 per cent in the case of the rump to 18.68 per cent in the case of the round. These changes are in conformity with similar changes observed in the autolysis experiment, and may be regarded as due to the action of phosphatases upon organic phosphorous compounds.

Soluble organic phosphorus shows changes that are opposite in character to those observed in case of the inorganic phosphorus. There were marked relative decreases in organic phosphorus ranging from 28.01 per cent in the case of the round to 46.47 per cent in the case of the rump. Changes in organic phosphorus do not, as a rule, constitute as true an index of the extent of organic phosphorous cleavage as do the corresponding changes in inorganic phosphorus.

EXPERIMENT NO. 2.

HISTORY OF CARCASS.

A "grade" Shorthorn steer of fair quality and finish was slaughtered in the usual manner. The carcass was allowed to hang for 2 hours on the killing floor, after which it was transferred to the fore cooler, where it was held for 17 hours, and then to the main cooler, where it was held for 29 hours. The temperature of the fore cooler ranged from 31° to 43° F. and that of the main cooler from 25° to 30° F. The humidity of the fore cooler was 95 per cent of saturation and that of the main cooler ranged from 75 to 95 per cent. After having been 46 hours in storage in the packing-house coolers, the two hind quarters of the carcass were carefully wrapped in cheesecloth and paper and transported by motor truck to the bureau's cold-storage rooms, the trip requiring about an hour. The weight of the carcass before chilling was 715 pounds.

STORAGE.

The quarters of beef were placed in cold-storage room No. 1, unwrapped, and hung up until the next day, when the right hind quarter was prepared for analysis. The total preliminary storage period of this quarter amounted to 65 hours. The left hind quarter was held in cold storage for an additional period of 28 days, during which period the temperature of the cold-storage room was quite uniform, ranging from 32° to 36° F. The humidity varied between 69 and 73 per cent of saturation.

After 21 days in cold storage the quarter of beef showed appreciable evidences of desiccation, the connective-tissue membrane over the surface of the quarter having become dry and parchmentlike and the exposed muscular tissue having undergone appreciable shrinkage. There was no mold on the outside of the quarter, and only a slight growth on the inside of the flank, where there was also a slight odor of incipient putrefaction.

At the end of 28 days in cold storage the quarter of beef showed practically the same characteristics as noted above. The total shrinkage in weight amounted to 5.26 per cent.

QUALITY OF MEAT.

Fresh quarter, in storage 65 hours.—This quarter of beef was not of as good quality as that from carcass No. 1, being not as well finished nor of as good conformation. As regards market classsification, this quarter would have been classed as "good." The following are the reports of the judges upon the organoleptic properties of the broiled test steak:

Mr. A.—The loin and tenderloin portions of the steak have a good flavor, but are not very juicy and are decidedly tough. The flank portion is extremely tough.

Mr. B.—The steak has a good flavor and is juicy, but all portions are rather tough; the tenderloin is not tender, but can be masticated; the loin portion is rather tough; and the flank portion is of rubbery consistency and can scarcely be eaten.

Mr. C.—All portions of the steak have a good flavor, but the tenderloin is slightly tough, the loin portion quite tough, and the flank end is very tough and of rubbery consistency.

Quarter of beef stored 30 days 17 hours.—As the quarter was being divided into wholesale cuts it was noticed that the flank was dry and hard. The cut surface of the flank was bright red in color. There was a slight odor of putrefaction from the exposed inner surface of the flank, although the cut surface had the normal odor.

The cut surface at the butt of the round had the normal odor and color. Where the muscular tissue had not been covered with fat and had been exposed to the air there was a hard dark-brown layer about one-eighth of an inch deep, due to desiccation, but no odor of putrefaction. The loin was in first-class condition, although the tip end, where the muscles had been exposed and had become dried out, required a little trimming. The kidney fat showed a slight growth of mold and had a rather strong odor. On the whole, this quarter of beef was considered to be in good marketable condition. The greatest apparent effect of storage upon the meat was that of desiccation.

When the meat was being prepared for analysis it was noted that the bundles of muscles separated with much greater ease than in the case of the fresh quarter of beef, and that apparently a marked softening of the intervening connective tissue had occurred.

The opinions of the respective judges concerning the quality of the broiled test steak are given below:

Mr. A.—The tenderloin portion is of good quality, has a good flavor, and is more tender than the steak from the fresh quarter. The meat is rather dry. The loin portion is much more tender than that of the fresh quarter, and is now quite palatable. While not first class, the meat is fairly tender and has a good flavor. The flank portion is decidedly more tender than in case of the fresh quarter and is now fairly palatable. The meat is rather dry, the flavor is fair, and the muscle fibers are coarse and tough.

Mr. B.—The steak is greatly improved in quality as compared with the steak from the fresh quarter of beef. While the meat is not of the highest quality, yet it has so improved in tenderness that even the flank portion can be eaten with ease.

Mr. C.—This steak is much better in quality in every respect than the steak from the fresh quarter of beef. The tenderloin is very tender, the loin portion is not quite as tender, and the flank end is fairly tender. The flavor of the steak is good.

CHEMICAL EXAMINATION OF CARCASS NO. 2.

Tables 19 to 25, inclusive, show the changes that occurred in the composition of carcass No. 2 during 28 days in cold storage.

Table 19 shows the composition of the carcass expressed in terms of percentages of fresh material. For reasons previously given these data will not be discussed.

Table 20 shows the composition of the carcass expressed in terms of percentages of the moisture-free and fat-free material. There are slight losses of moisture due to evaporation during storage, and insignificant changes in ash. Changes in nitrogen and phosphorous compounds will be discussed in connection with Tables 24 and 25.

Table 21 shows the composition of the 0.9 per cent sodium chlorid extract expressed in terms of percentages of the fresh material. These data will be discussed as recalculated in Table 22.

TABLE 19.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D. H.								
13	Round: Right hind quarter.	2 17	75.68	1.85	1.06	3.40	0.0083	0.202	0.154	0.048
25	Round: Left hind quarter...	30 17	75.24	1.70	1.07	3.45	.0101	.202	.158	.044
14	Rump: Right hind quarter..	2 17	74.92	3.07	1.03	3.27	.0074	.200	.147	.053
26	Rump: Left hind quarter...	30 17	74.36	3.34	1.03	3.28	.0093	.192	.143	.049
15	Loin: Right hind quarter...	2 17	74.54	3.71	1.01	3.27	.0072	.192	.145	.047
27	Loin: Left hind quarter.....	30 17	73.98	3.64	1.02	3.35	.0085	.187	.146	.041

TABLE 20.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
13	Round: Right hind quarter.	2 17	77.11	4.72	15.14	0.0367	0.897	0.687	0.210
25	Round: Left hind quarter...	30 17	76.54	4.62	14.97	.0439	.877	.687	.190
	Change..................	28	−0.57	−0.10	−0.17	+.0072	−.020	.000	−.020
14	Rump: Right hind quarter..	2 17	77.29	4.68	14.86	.0334	.910	.668	.242
26	Rump: Left hind quarter....	30 17	76.93	4.64	14.77	.0417	.859	.642	.217
	Change..................	28	−0.36	−0.04	−0.09	+.0083	−.051	−.026	−.025
15	Loin: Right hind quarter....	2 17	77.41	4.64	15.01	.0330	.881	.668	.213
27	Loin: Left hind quarter.....	30 17	76.77	4.54	14.95	.0379	.837	.651	.186
	Change..................	28	−0.64	−0.10	−0.06	+.0049	−.044	−.017	−.027

Table 22 shows the composition of the sodium chlorid extract expressed in terms of percentages of the moisture-free and fat-free material.

Appreciable decreases have taken place in total solids, and slight decreases in organic extractives, that are similar to the changes noted in Experiment No. 1 and in the autolysis experiment.

Ash of extract shows appreciable decreases, but these changes are not of great significance for reasons previously noted.

Changes in acidity are irregular and without apparent significance.

Changes in nitrogen and phosphorus compounds will be discussed in connection with Tables 24 and 25.

Table 23 shows the composition of the fat at the beginning and end of the storage period.

All samples show appreciable increases in acidity ranging from 0.68 per cent in the case of the kidney fat to 1.24 per cent in the case of the external fat. The increase in the acidity of the intermuscular fat may be regarded as being due to the action of the enzym lipase

TABLE 21.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
13	Round: Right hind quarter	2 17	6.75	1.09	5.66	0.75	0.967	0.556	0.411	0.024	0.086	0.154	0.128	0.026
25	Round: Left hind quarter	30 17	6.80	1.01	5.79	.81	.968	.475	.493	.058	.110	.158	.142	.016
14	Rump: Right hind quarter	2 17	6.75	0.98	5.77	.75	.936	.519	.417	.029	.085	.147	.111	.036
26	Rump: Left hind quarter	30 17	6.64	0.90	5.74	.72	.925	.452	.473	.057	.110	.143	.125	.018
15	Loin: Right hind quarter	2 17	6.85	0.97	5.88	.73	.949	.547	.402	.018	.094	.145	.106	.039
27	Loin: Left hind quarter	30 17	6.87	0.87	6.00	.70	.982	.525	.457	.052	.095	.146	.128	.018

TABLE 22.—*Composition of 0.9 per cent sodium chlorid extract of meat, expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
13	Round: Right hind quarter	2 17	30.02	4.83	25.19	3.34	4.30	2.48	1.82	0.105	0.3813	0.687	0.570	0.117
25	Round: Left hind quarter	30 17	29.47	4.38	25.09	3.51	4.20	2.06	2.14	.252	.4752	.687	.615	.072
	Change	28	−0.55	−0.45	−0.10	+0.17	−0.10	−0.42	+0.32	+0.147	+.0939	.000	+.045	−.045
14	Rump: Right hind quarter	2 17	30.67	4.43	26.24	3.41	4.25	2.36	1.89	.130	.3875	.668	.502	.166
26	Rump: Left hind quarter	30 17	29.75	4.04	25.71	3.21	4.15	2.03	2.12	.256	.4910	.642	.561	.081
	Change	28	−0.92	−0.39	−0.53	−0.20	−0.10	−0.33	+0.23	+0.126	+.1035	−.026	+.059	−.085
15	Loin: Right hind quarter	2 17	31.48	4.46	27.02	3.35	4.36	2.51	1.85	.083	.4320	.668	.489	.179
27	Loin: Left hind quarter	30 17	30.69	3.89	26.80	3.13	4.39	2.34	2.05	.232	.4250	.651	.574	.077
	Change	28	−0.79	−0.57	−0.22	−0.22	+0.03	−0.17	+0.20	+.149	−.0070	−.017	+.085	−.102

upon the neutral fats, while the greater increase in acidity of the external fat is probably due to combined bacterial and enzym action.

The external and kidney fats had developed a rather strong flavor at the end of the storage period.

TABLE 23.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40°C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. H.					
16	Kidney fat: Right hind quarter..	2 17	37.40	1.4560	0.34	Neg.....	Normal.
28	Kidney fat: Left hind quarter....	30 17	37.59	1.4560	1.02	...do.....	Somewhat strong flavor and odor.
17	Intermuscular fat: Right hind quarter.	2 17	44.79	1.4568	.28	...do.....	Normal.
28	Intermuscular fat: Left hind quarter.	30 17	45.09	1.4568	1.02	...do.....	Do.
18	External fat: Right hind quarter.	2 17	52.20	1.4574	.28	...do.....	Do.
30	External fat: Left hind quarter...	30 17	50.63	1.4574	1.52	...do.....	Somewhat strong flavor and odor.

Table 24 shows the distribution of nitrogen and phosphorus in the meat on the basis of 100 parts of the respective constituents in the material at the beginning of the storage period.

Total nitrogen shows slight changes which are without apparent significance.

There are appreciable decreases in the soluble nitrogen in case of the round and the rump and there is a slight increase in case of the loin. Changes in the soluble-nitrogen content of the round and the rump are similar to the changes in this constituent noted in the early stages of the autolysis experiment and in experiment No. 1, and they may be explained in the same manner.

Coagulable nitrogen shows quite marked decreases, and opposite changes are noted in the noncoagulable nitrogen.

Proteose nitrogen shows marked relative increases that range from 96.92 per cent in the case of the rump to 179.52 per cent in the case of the loin. However, by referring to Table 22, it may be noted that the actual amounts of proteoses present are quite small.

Amino nitrogen in the round and rump increased by approximately 25 per cent, while that in the loin decreased by an amount that was practically within the limit of experimental error. These results indicate a general increase in this constituent, which is in conformity with results obtained in the autolysis experiment.

Ammoniacal nitrogen increased distinctly during the storage period in each of the three portions of the carcass analyzed. The increases ranged from 15.51 per cent in the case of the loin to 24.85 per cent in the case of the rump, the minimum increase in this experiment being greater than the maximum increase that occurred in experiment No. 1. These results are in conformity with those obtained in the autolysis experiment.

Slight apparent decreases, which for the present must be regarded as due to possible inequalities in sampling, have taken place in the total phosphorus. On account of the effect of the decreases in total phosphorus upon the value of the other phosphorous compounds, changes in those constituents will be discussed in connection with Table 25.

Table 25 shows the distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus.

The distribution of the nitrogen compounds does not differ greatly from that in case of experiment No. 1. There is an appreciable increase in the proportion of total nitrogen present as soluble, noncoagulable, proteose, and ammoniacal nitrogen, and a decrease in the proportion present as coagulable nitrogen.

Insoluble phosphorus shows appreciable decreases that range from 5.22 per cent in case of the rump to 8.58 per cent in case of the loin. These results appear to be in conformity with the findings obtained in the autolysis experiment, but in view of the results obtained in other experiments of this series this seeming conformity must be regarded as accidental.

Total soluble phosphorus shows increases corresponding to the decreases in insoluble phosphorus.

Soluble inorganic phosphorus shows appreciable increases, which range from 10.37 per cent in the case of the round to 23.47 per cent in the case of the loin. On the whole the increases in soluble inorganic phosphorus are but slightly greater than similar changes in this constituent in Experiment No. 1. On account of the much longer storage period in Experiment No. 2 a larger increase in inorganic phosphorus might have been expected; but in this connection it is interesting to note that the material used for this experiment already contained a considerably higher percentage of preformed inorganic phosphorus than did the material used in the first experiment. It would appear as though the larger quantity of inorganic phosphorus present in the material used in the second experiment either of itself retarded the rate of change of organic phosphorus into inorganic forms or was indicative of some retarding agency.

Interesting light is thrown on this question by the results of the autolysis experiment, as shown in Table 11, where under the heading "Inorganic phosphorus" it may be noted that the increase in this constituent takes place most rapidly during the first 7 days of the experiment. Thus during the first 7 days the relative increase amounts to 52.78 per cent, while during the total incubation period of 100 days the relative increase amounts to only 65.27 per

TABLE 24.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. *H.*												
13	Round: Right hind quarter	2 17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
25	Round: Left hind quarter	30 17	98.88	97.67	83.06	117.58	240.00	124.63	119.62	97.74	90.37	99.98	107.86	61.62
14	Rump: Right hind quarter	2 17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
26	Rump: Left hind quarter	30 17	99.39	97.65	86.02	112.17	196.92	126.71	124.85	94.38	89.44	96.18	111.77	48.79
15	Loin: Right hind quarter	2 17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
27	Loin: Left hind quarter	30 17	99.60	100.69	93.23	110.81	279.52	98.38	115.51	94.96	86.84	97.56	117.29	43.10

TABLE 25.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. *H.*												
13	Round: Right hind quarter	2 17	100.00	28.40	16.38	12.02	0.69	2.52	0.24	100.00	23.40	76.60	63.56	13.04
25	Round: Left hind quarter	30 17	100.00	28.06	13.76	14.30	1.68	3.17	.29	100.00	21.62	78.38	70.15	8.23
	Change	28	0.00	−1.20	−16.00	+18.92	+142.73	+26.04	+21.00	0.00	−7.61	+2.32	+10.37	−36.89
14	Rump: Right hind quarter	2 17	100.00	28.60	15.88	12.72	.87	2.61	.22	100.00	26.64	73.36	55.21	18.15
26	Rump: Left hind quarter	30 17	100.00	28.10	13.74	14.36	1.73	3.32	.28	100.00	25.25	74.75	65.37	9.38
	Change	28	0.00	−1.76	−13.46	+12.85	+98.89	+27.48	+25.57	0.00	−5.22	+1.90	+18.40	−48.26
15	Loin: Right hind quarter	2 17	100.00	29.05	16.72	12.33	.55	2.88	.22	100.00	24.24	75.76	55.52	20.24
27	Loin: Left hind quarter	30 17	100.00	29.36	15.65	13.71	1.55	2.84	.25	100.00	22.16	77.84	68.55	9.29
	Change	28	0.00	+1.09	−6.40	+11.25	+180.65	−1.23	+15.16	0.00	−8.58	+2.75	+23.47	−54.10

cent, so that 80.9 per cent of the total increase in inorganic phosphorus has taken place in the first 7 days and 19.1 per cent in the remaining 93 days. These facts indicate very clearly that the rate of the enzymatic change of organic phosphorus to inorganic forms decreases as the reaction progresses. It is, therefore, not surprising that the cleavage of the organic phosphorus took place rather slowly in this experiment where the phosphorus distribution in the material used approximated to that obtaining in meat which has already undergone a certain amount of autolysis. The exact cause of the retarded rate of change, however, remains to be determined.

Soluble organic phosphorus shows large relative decreases that vary from 36.89 per cent in the case of the round to 54.10 per cent in the case of the loin. However, the actual decreases are only slightly greater than those observed in the carcass stored for two weeks in Experiment No. 1. The apparent explanation for the slower rate of change of organic phosphorus into inorganic forms has already been discussed under inorganic phosphorus.

EXPERIMENT NO. 3.

HISTORY OF CARCASS.

A "grade" shorthorn steer 4½ years old and of fair conformation and finish, was slaughtered in the usual manner and the carcass was allowed to hang for 50 minutes on the killing floor, after which it was run into the cooler. The warm carcass weighed 755 pounds. The carcass was held for 22 hours in the fore cooler at a temperature between 30° and 36° F., and for 48 hours in the main cooler at a temperature varying from 30° to 32° F. The humidity of the fore cooler was 95 per cent and that of the main cooler 98 per cent of saturation. After storage for 70 hours in the packing-house coolers the two hind quarters of the carcass were carefully wrapped and transported to the bureau's cold-storage rooms, the trip requiring less than one hour.

STORAGE.

The quarters of beef were unwrapped and weighed, and one was immediately prepared for analysis while the other was hung up in cold-storage room No. 1 for a period of 42 days.

The temperature of the cold-storage room was fairly uniform throughout this experiment, ranging from 32° to 36° F. The humidity varied from 69 to 74 per cent of saturation.

Observations as to the condition of the beef were made at intervals during the storage period, with the following results:

After 24 days in storage the beef was in good condition. There was a slight growth of mold on the outside and inside of the flank. The exposed cut muscular surfaces on the inside of the round and on the tip of the loin had become dark-brown in color and firm in textures. Exposed bundles of muscles at the shank had turned dark-brown in color.

After 31 days in storage the condition of the meat had not changed appreciably since the previous observation, except perhaps that evidences of desiccation had become more apparent.

At the end of the storage period of 42 days in the bureau's cooler, or after a total period of 45 days in cold storage, the beef was in good condition as regards state of preservation although it showed considerable drying out, particularly where the meat was not well covered with fat. There was also a slight growth of mold on the flank and "hanging tender" and a slightly musty odor at these points. The beef showed a shrinkage of 6.3 per cent during storage.

QUALITY OF MEAT.

Fresh quarter, in storage 71 hours.—This quarter was of fairly good quality as regards conformation and finish, being fairly well covered with fat, and would have been classed as "good." The judge's opinions regarding the quality of the broiled test steak cut from this quarter are as follows:

Mr. A.—The tenderloin is tender and of good flavor. The loin portion is much tougher than the tenderloin, while the flank end is too tough too eat. As a whole the steak has a good flavor.

Mr. B.—The steak is more tender than that from the corresponding quarter of carcass No. 2, but is less tender than that from carcass No. 1. The flavor is not as good as that of the steaks from the quarters of beef just described. As regards tenderness and palatability, the tenderloin ranks first and the flank end last.

Mr. C.—On the whole the steak is superior to the one from the corresponding quarter of carcass No. 2, but inferior to the one from carcass No. 1. The steak has a good flavor. The tenderloin is the most tender and the flank end the least so of the different parts of the steak.

Quarter of beef stored 45 days.—When the quarter of beef was cut up preparatory to analysis, the cut surface at the butt of the round was found to be bright-red in color except for a narrow dark band at the surface where the muscular tissue had been exposed to the air. Where the surface of the meat had been covered with fat there was only a trace of such a band. The freshly cut surface of the meat had an odor that was rather different from that of fresh meat and which might have been termed slightly "old," but which was in no sense an odor of putrefaction. When the loin was cut, it was found that the tenderloin was somewhat darkened around the outside and had a slightly "off" odor. The porterhouse steak cut for broiling had a rather "old" odor, particularly at the outer portion of the tenderloin and at the flank end where the odor was that of incipient putrefaction. On being cut and ground, the meat appeared to be comparatively tender. The kidney fat had a distinctly "old" and sour odor.

On the whole, this quarter of beef, which has been held in cold storage for a total period of 45 days, appeared to be in sound condition; but the market value of the beef was probably less than it would have been earlier in the storage period, principally because of the effects of desiccation upon the appearance of the meat. The organoleptic qualities of the broiled test steak cut from this quarter were reported upon by the respective judges as follows:

Mr. A.—The tenderloin portion is fairly tender and has a good flavor, except the outer portion, which has a rather "old" taste. The loin portion is fairly tender, but rather dry and lacking in flavor. Portions have an "old" taste. The flank end is tough and stringy and the flavor is not good.

Mr. B.—The steak is generally superior to the one cut from the corresponding quarter at the beginning of the storage period as regards tenderness, but inferior as regards flavor. Portions of the steak, particularly outer portions of the tenderloin and loin, are tainted and not edible. This "old" flavor might be called "gamey."

Mr. C.—This steak shows some signs of incipient putrefaction at the flank end and on the outside of the tenderloin. Changes are positive but not extensive. The tenderloin is quite tender and fairly juicy, but has an "old" flavor, and portions have a slightly "off" flavor.

CHEMICAL EXAMINATION OF CARCASS NO. 3.

Tables 26 to 32, inclusive, show the changes which took place in the composition of carcass No. 3 during 42 days of cold storage.

Table 26 shows the composition of the carcass expressed in terms of percentages of fresh material; but for reasons previously noted these data will not be discussed.

Table 27 shows the composition of the material expressed as percentages of moisture-free and fat-free material.

There are appreciable losses of moisture, which are slightly greater than similar losses observed in the case of the carcass stored 28 days.

There are slight changes in the ash, which have no significance.

The data for total nitrogen show appreciable losses, the significance of which is not yet apparent.

Changes in ammonia and in phosphorus compounds will be discussed in connection with Tables 31 and 32.

TABLE 26.—*Composition expressed in terms of percentage of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D. H.								
19	Round: Right hind quarter.	2 23	74.59	2.06	1.09	3.46	0.0102	0.209	0.163	0.046
38	Round: Left hind quarter...	44 23	74.15	1.96	1.11	3.48	.0122	.211	.165	.046
20	Rump: Right hind quarter..	2 23	73.79	3.19	1.06	3.39	.0102	.203	.157	.046
39	Rump: Left hind quarter...	44 23	73.32	3.27	1.06	3.36	.0116	.198	.148	.050
21	Loin: Right hind quarter...	2 23	73.50	4.17	1.03	3.30	.0094	.194	.152	.042
40	Loin: Left hind quarter.....	44 23	71.82	4.92	1.09	3.36	.0115	.197	.149	.048

TABLE 27.—*Composition expressed in terms of percentage of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
19	Round: Right hind quarter..	2 23	76.16	4.67	14.80	0.0435	0.893	0.698	0.195
38	Round: Left hind quarter...	44 23	75.63	4.65	14.58	.0510	.881	.691	.190
	Change..................	42	−0.53	−0.02	−0.22	+.0075	−.012	−.007	−.005
20	Rump: Right hind quarter..	2 23	76.22	4.60	14.73	.0445	.882	.680	.202
39	Rump: Left hind quarter....	44 23	75.80	4.53	14.32	.0494	.845	.631	.214
	Change..................	42	−0.42	−0.07	−0.41	+.0049	−.037	−.049	+.012
21	Loin: Right hind quarter....	2 23	76.70	4.59	14.75	.0420	.868	.682	.186
40	Loin: Left hind quarter......	44 23	75.54	4.67	14.43	.0495	.845	.643	.202
	Change..................	42	−1.16	+0.08	−0.32	+.0075	−.023	−.039	+.016

Table 28 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the fresh material. These data will be discussed as recalculated in Table 29.

Table 29 shows the composition of the sodium chlorid extract expressed in terms of percentages of the moisture-free and fat-free material.

Total solids show irregular changes which apparently have no significance.

Changes in ash of extract are so great that they must be regarded with suspicion.

There are appreciable and regular losses in soluble phosphorus, but not such as would account for the large apparent losses in total soluble ash.

The apparent changes in organic extractives, i. e., in the differences between total solids and total ash, must also be regarded with suspicion.

There is a slight increase in the acidity on the whole.

Table 30 shows the changes in the composition of the fat during storage. The most marked changes which have taken place are those which occurred in the acidity of the samples. The intermuscular fat shows a small increase amounting to 0.45 per cent, which is appreciably less than that which took place in the meat stored four weeks, as may be seen by referring to Table 23. Owing to the protected position of the fatty tissue, this increase in acidity may be regarded as due, in large part at least, to enzym action.

Kidney and external fat show large actual increases in acidity, amounting to 3.28 and 3.45 per cent, respectively. These increases, which are large as compared with the small increase in case of the intermuscular fat, may be explained by the fact that the kidney and the external fat are exposed to bacterial invasion, and that the hydrol-

TABLE 28.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period. D. H.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
19	Round: Right hind quarter	2 23	6.96	1.19	5.77	0.77	0.947	0.514	0.433	0.029	0.0871	0.163	0.103	0.060
38	Round: Left hind quarter	44 23	7.25	.86	6.39	.85	1.01	.487	.523	.063	.1208	.165	.135	.030
20	Rump: Right hind quarter	2 23	6.99	.99	6.00	.70	.958	.531	.427	.031	.0852	.157	.098	.059
39	Rump: Left hind quarter	44 23	7.07	.66	6.41	.74	.988	.477	.511	.062	.1203	.148	.125	.023
21	Loin: Right hind quarter	2 23	6.81	.98	5.83	.71	.950	.529	.421	.027	.0848	.152	.094	.058
40	Loin: Left hind quarter	44 23	7.01	.76	6.25	.70	.996	.519	.477	.054	.1144	.149	.127	.022

TABLE 29.—*Composition of 0.9 per cent sodium chlorid extract of meat, expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period. D. H.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
19	Round: Right hind quarter	2 23	29.81	5.10	24.71	3.28	4.06	2.20	1.86	0.125	0.3731	0.698	0.441	0.257
38	Round: Left hind quarter	44 23	30.34	3.58	26.76	3.54	4.23	2.04	2.19	.261	.5055	.691	.565	.126
	Change	42	+0.53	−1.52	+2.05	+0.26	+0.17	−0.16	+0.33	+.136	+.1324	−.007	+.124	−.131
20	Rump: Right hind quarter	2 23	30.34	4.28	26.06	3.02	4.16	2.31	1.85	.134	.3702	.680	.428	.252
39	Rump: Left hind quarter	44 23	30.20	2.82	27.38	3.14	4.22	2.04	2.18	.263	.5138	.631	.535	.096
	Change	42	−0.14	−1.46	+1.32	+0.12	+0.06	−0.27	+0.33	+.129	+.1436	−.049	+.107	−.156
21	Loin: Right hind quarter	2 23	30.48	4.37	26.11	3.18	4.26	2.37	1.89	.123	.3798	.682	.420	.262
40	Loin: Left hind quarter	44 23	30.14	3.27	26.87	3.01	4.28	2.23	2.05	.233	.4918	.643	.545	.098
	Change	42	−0.34	−1.10	+0.76	−0.17	+0.02	−0.14	+0.16	+.110	+.1120	−.039	+.125	−.164

ysis of these fats, therefore, is due largely to bacterial action. The kidney and external fats are of poor quality, having a strong disagreeable odor and flavor, while the intermuscular fat is of a fair quality.

TABLE 30.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40°C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. H.					
22	Kidney fat: Right hind quarter..	2 23	42.53	1.4560	0.39	Neg.....	Normal.
41	Kidney fat: Left hind quarter....	44 23	41.87	1.4568	3.67	...do.....	Rather strong odor and flavor.
23	Intermuscular fat: Right hind quarter.	2 23	49.34	1.4572	.45	...do.....	Normal.
42	Intermuscular fat: Left hind quarter.	44 23	49.18	1.4578	.90	...do.....	Slightly meaty flavor. Better than 41 and 43.
24	External fat: Right hind quarter.	2 23	55.96	1.4578	.39	...do.....	Normal.
43	External fat: Left hind quarter...	44 23	56.83	1.4583	3.84	...do.....	Rather strong odor and flavor.

Table 31 shows the distribution of the nitrogen and phosphorous compounds upon the basis of 100 parts of the respective constituents in the material at the beginning of the storage period.

Changes in total nitrogen have been previously noted.

Total soluble nitrogen shows appreciable but irregular increases, ranging from 0.47 per cent in the case of the loin to 4.19 per cent in the case of the round; whereas carcass No. 1 stored for two weeks and carcass No. 2 stored for four weeks each showed decreases in total soluble nitrogen at the end of their respective storage periods.

Coagulable nitrogen shows fairly marked decreases, but on account of the increases in total soluble nitrogen, these data do not indicate the full extent of the changes, which are shown more clearly under noncoagulable nitrogen.

Noncoagulable nitrogen shows appreciable increases which are slightly greater, on the whole, than those observed in the case of carcass No. 2, which was stored for four weeks.

There are marked relative increases in proteose nitrogen, which are greater than those that took place in carcass No. 1, which was stored for two weeks, but less than those that occurred in carcass No. 2, which was stored for four weeks.

Amino nitrogen increased decidedly during the storage period in each portion of the carcass analyzed, the minimum increase in this experiment being greater than the maximum increase that occurred during the shorter periods of storage. This is in continued conformity with the results obtained in the autolysis experiment.

Ammoniacal nitrogen increased appreciably during the storage period in each of the cuts analyzed; yet, on the whole, the increases

TABLE 31.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluable.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
19	Round: Right hind quarter	2 23	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
38	Round: Left hind quarter	44 23	98.51	104.19	92.73	117.74	208.80	135.48	117.24	98.71	98.00	98.91	128.14	48.87
20	Rump: Right hind quarter	2 23	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
39	Rump: Left hind quarter	44 23	97.22	101.44	88.31	117.84	196.27	138.79	111.01	95.79	106.24	92.69	125.19	37.69
21	Loin: Right hind quarter	2 23	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
40	Loin: Left hind quarter	44 23	97.83	100.47	94.09	108.47	189.43	129.49	117.86	97.34	108.87	94.19	129.78	37.27

TABLE 32.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluable.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
19	Round: Right hind quarter	2 23	100.00	27.43	14.86	12.57	0.845	2.52	0.294	100.00	21.81	78.19	49.36	28.83
38	Round: Left hind quarter	44 23	100.00	29.01	13.99	15.02	1.790	3.47	.350	100.00	21.66	78.34	64.07	14.24
	Change, per cent	42	0.00	+5.76	−5.87	+19.51	+111.95	+37.53	+19.00	0.00	− .69	+ .19	+29.80	−50.61
20	Rump: Right hind quarter	2 23	100.00	28.24	15.68	12.56	.910	2.51	.302	100.00	22.90	77.10	48.47	28.63
39	Rump: Left hind quarter	44 23	100.00	29.47	14.24	15.23	1.837	3.59	.345	100.00	25.39	74.61	63.35	11.26
	Change, per cent	42	0.00	+4.35	−9.16	+21.20	+101.89	+42.76	+14.19	0.00	+10.87	−3.23	+30.70	−60.71
21	Loin: Right hind quarter	2 23	100.00	28.88	16.07	12.81	.834	2.58	.285	100.00	21.42	78.58	48.35	30.23
40	Loin: Left hind quarter	44 23	100.00	29.66	15.45	14.21	1.615	3.41	.343	100.00	23.97	76.03	64.46	11.57
	Change, per cent	42	0.00	+2.70	−3.82	+10.86	+ 93.63	+32.36	+20.38	0.00	+11.91	−3.25	+33.32	−61.73

were less than the corresponding increases noted in experiment No. 2. This, however, is not surprising in view of the larger amount of preformed ammonia in the material used for this experiment, especially since the results of the autolysis experiment go to show that the rate of formation of this product tends to decrease as the product itself accumulates.

Slight decreases in total phosphorus are without apparent significance.

Table 32 shows the distribution of nitrogen and phosphorus expressed in terms of percentages of total nitrogen and total phosphorus.

The data for nitrogen show that at the end of the storage period an appreciably larger proportion of the total nitrogen was present in the form of total soluble nitrogen, and as proteose, noncoagulable, amino, and ammoniacal nitrogen, than was present in the meat from carcass No. 2, which had been stored for four weeks. These facts indicate that the proteolytic changes had made appreciable progress during the longer storage period of carcass No. 3.

There are fairly marked increases in insoluble phosphorus in the rump and in the loin, and a slight decrease in the round. An increase in this constituent was hardly to have been expected, and there seems to be no apparent explanation for the change.

There are slight changes in soluble phosphorus which must be regarded as having no significance.

Soluble inorganic phosphorus shows increases amounting to approximately 30 per cent of the amount present in the meat at the beginning of the storage period, which increases are considerably larger than those observed in the carcasses stored either for two weeks or for four weeks. These changes are in conformity with those that occurred during the autolysis experiment.

In the soluble organic phosphorus there are pronounced decreases that are appreciably larger than those noted in case of the carcasses stored for shorter periods of time. These changes also are similar to those observed in the autolysis experiment.

EXPERIMENT NO. 4.

HISTORY OF CARCASS.

A "grade" shorthorn steer $3\frac{1}{2}$ years old and of fair quality and finish was slaughtered by the usual methods and the carcass was allowed to hang 45 minutes on the killing floor, after which it was run into the cooler. The warm carcass weighed 845 pounds. The carcass was held 19 hours in the fore cooler having a temperature between 30° and 41° F., and 51 hours in the main cooler, the temperature of which remained at 29° F. The humidity of the fore cooler was 97 per cent and that of the main cooler 95 per cent of saturation. After storage for 70 hours in the packing-house coolers, the hind quarters of the carcass were carefully wrapped and transported to the bureau's cooler, the trip requiring less than an hour.

STORAGE.

The quarters of beef were unwrapped and weighed; one quarter was hung up in cold-storage room No. 1 for a period of 63 days; the other was prepared immediately for analysis.

The temperature of the cold-storage room was fairly uniform, ranging between 34° and 37° F. during the greater part of the experiment. On one occasion, for a period of about a day, the temperature ran up to 40° F. owing to difficulties with the refrigerating equipment. The humidity of the cold-storage room ranged from 69.5 to 73.5 per cent of saturation, except that when the temperature rose to 40° F. the humidity was increased to 82 per cent by the melting of the ice from the coils.

While observations as to the condition of the beef in storage were made at approximately weekly intervals during the storage period, only a few of the observations will be reported.

After 24 days in storage the quarter of beef was in normal condition. The flank showed slight desiccation and a trace of mold. At the end of 38 days in storage the beef was in very good condition. There was a slight growth of mold on the exposed muscular tissue at the inside of the butt of the round and a trace only on the flank, which had become rather hard and dry. After 52 days in storage the beef had begun to look rather old and showed considerable desiccation, particularly the flank, which had become quite hard and dry. There was a very slight growth of mold on the flank. The beef had a rather "old" odor, but not that of putrefaction.

At the end of the storage period, or after storage for 63 days in the bureau's cooler, the quarter of beef had practically the same appearance as noted at the end of 52 days in storage. An experienced meat inspector whose daily work brought him in contact with chilled beef as it is handled on the market examined this quarter of beef at the end of the storage period and stated that he considered it to be in first-class condition.

QUALITY OF MEAT.

Fresh quarter, stored 73 hours.—This quarter was of fairly good quality as regards form and finish and was well covered with fat, except a portion toward the shank. As regards market classification the quarter would have been classed "good." The broiled test steak cut from this quarter was described by the respective judges as follows:

Mr. A.—The tenderloin is quite tender, the loin portion rather tough, and the flank end very tough. The steak is juicy and has a good flavor.

Mr. B.—On the whole the steak is of excellent quality but shows lack of ripening. The tenderloin and loin portions of the steak are fairly tender.

Mr. C.—The tenderloin is quite tender, the loin portion rather tough, and the flank portion fairly tender. The steak is juicy and has a good flavor.

Quarter of beef stored 66 days.—When this quarter of beef was being cut up preparatory to analysis the following observations were made: The cut surface at the butt of the round had a bright-red color and a sweet odor, but one which was distinctly different from that of fresh beef. Where the muscular tissue had not been covered with fat and had been exposed to the air there was a narrow dark-brown zone at the surface of the meat. The tip end of the loin, where the cut surface had been exposed to the air, was dark-brown in color and had a strong odor. After cutting off a slice about 1 inch thick from the tip of the loin, so as to remove the dried portion, the fresh-cut surface of the loin had a dark-red color and a rather strong but not a putrefactive odor. As successive cuts were made toward the butt of the loin the color of each successive surface was found to be brighter and its odor less pronounced. While the meat was being cut it was also found that the bundles of muscles could be separated much more easily than was the case with those of the fresh quarter of beef, a fact which indicated a marked softening of the connective tissues. The meat "handled" as though it were quite tender.

The kidney fat was in poor condition, being hard and dry and badly discolored. Throughout the mass there was evidence of a widely distributed growth of mold.

The freshly cut test steak had a rather strong odor which largely disappeared on broiling. The color of the meat was rather darker than that of the steak cut from the fresh quarter of beef. The organoleptic qualities of the broiled steak were described by the three judges as follows:

Mr. A.—The tenderloin portion is fairly tender and has a good flavor, but is rather dry. The loin portion is not as tender as the tenderloin and is rather dry, but has a good flavor. The flank end is very tough and has an "old" taste.

Mr. B.—The tenderloin portion is very tender, but has a disagreeable so-called "gamey" flavor. The loin portion is not very tender and the flavor is not disagreeable. The flank portion is fairly tender and palatable.

Mr. C.—The tenderloin and loin portions are very tender and juicy and have a good flavor. The flank end of the steak is fairly tender and juicy, but has a rather strong "gamey" flavor and is not very palatable. On the whole this steak is not as palatable as the steaks cut from the quarters of beef that had been stored for shorter periods of time.

CHEMICAL EXAMINATION OF CARCASS NO. 4.

Tables 33 to 39, inclusive, show the changes that took place in the composition of carcass No. 4 during 63 days in cold storage.

Table 33 shows the composition of the carcass expressed in terms of percentages of the fresh material.

Table 34 shows the composition of the carcass expressed in terms of percentages of the moisture-free and fat-free material.

There are appreciable losses of moisture which are somewhat greater, on the whole, than those observed in the case of carcass No. 3, stored 42 days.

Slight changes in the ash are without significance.

The data for total nitrogen seem to show appreciable decreases in this constituent. The fact that similar, though smaller, decreases were noted in the nitrogen content of carcasses Nos. 2 and 3, stored for 28 and 42 days, respectively, makes it appear that these apparent losses of nitrogen from the meat during storage may have some significance.

TABLE 33.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.		Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
									Total.	Soluble.	Insoluble.
		D.	*H.*								
31	Round: Right hind quarter.	3	1	74.51	2.85	1.06	3.52	0.0103	0.202	0.156	0.046
50	Round: Left hind quarter...	65	22	73.40	3.15	1.07	3.51	.0134	.199	.157	.042
32	Rump: Right hind quarter.	3	1	73.01	4.77	1.04	3.30	.0100	.197	.150	.047
51	Rump: Left hind quarter...	65	22	71.50	5.73	1.04	3.37	.0132	.186	.145	.041
33	Loin: Right hind quarter...	3	1	71.37	6.98	.99	3.28	.0092	.189	.144	.045
52	Loin: Left hind quarter.....	65	22	70.10	7.41	1.06	3.31	.0115	.181	.136	.045
34	Flank: Right hind quarter..	3	1	71.56	5.81	1.02	3.51	.0088	.184	.148	.031
53	Flank: Left hind quarter...	65	22	55.49	13.37	1.39	4.72	.0178	.237	.186	.056

TABLE 34.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.		Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D.	*H.*							
31	Round: Right hind quarter.	3	1	76.69	4.68	15.53	0.0452	0.891	0.687	0.204
50	Round: Left hind quarter...	65	22	75.78	4.56	14.96	.0572	.849	.667	.182
	Change...............	62	21	– 0.91	– 0.12	– 0.57	+ .0120	– .042	– .020	– .022
32	Rump: Right hind quarter..	3	1	76.67	4.66	14.86	.0449	.887	.675	.212
51	Rump: Left hind quarter...	65	22	75.84	4.57	14.77	.0580	.818	.637	.181
	Change...............	61	21	– 0.83	– 0.09	– 0.09	+ .0131	– .069	– .038	– .031
33	Loin: Right hind quarter....	3	1	76.73	4.57	15.15	.0425	.871	.664	.207
52	Loin: Left hind quarter.....	65	22	75.70	4.69	14.71	.0513	.806	.605	.201
	Change...............	62	21	– 1.03	+ 0.12	– 0.44	+ .0088	– .065	– .059	– .006
34	Flank: Right hind quarter..	3	1	75.97	4.51	15.49	.0390	.811	.654	.157
53	Flank: Left hind quarter....	65	22	64.05	4.45	15.16	.0572	.762	.597	.165
	Change...............	62	21	–11.92	– 0.06	– 0.33	+ .0182	– .049	– .057	+ .008

TABLE 35.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
		D.	H.					Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
31	Round: Right hind quarter	3	1	7.65	1.01	6.64	0.64	1.12	0.700	0.420	0.038	0.0896	0.156	0.129	0.027
50	Round: Left hind quarter	65	22	7.62	.97	6.65	.74	1.12	.566	.554	.048	.1434	.157	.150	.007
32	Rump: Right hind quarter	3	1	7.37	.92	6.45	.63	1.07	.646	.424	.039	.0883	.150	.121	.029
51	Rump: Left hind quarter	65	22	7.47	.90	6.57	.70	1.08	.574	.506	.050	.1456	.145	.132	.013
33	Loin: Right hind quarter	3	1	7.46	.96	6.50	.61	1.08	.661	.419	.035	.0847	.144	.118	.026
52	Loin: Left hind quarter	65	22	7.25	.80	6.45	.64	1.07	.561	.509	.044	.1386	.136	.129	.007
34	Flank: Right hind quarter	3	1	7.44	1.01	6.43	.65	1.08	.687	.393	.030	.0816	.148	.127	.021
53	Flank: Left hind quarter	65	22	9.04	.87	8.17	.86	1.36	.725	.635	.044	.1572	.186	.176	.010

TABLE 36.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
		D.	H.					Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
31	Round: Right hind quarter	3	1	33.77	4.44	29.33	2.83	4.95	3.09	1.86	0.166	0.3959	0.687	0.571	0.116
50	Round: Left hind quarter	65	22	32.48	4.11	28.37	3.13	4.76	2.41	2.35	.204	.6114	.667	.637	.030
	Change	62	21	−1.29	−0.33	−0.96	+0.30	−0.19	−0.68	+0.49	+ .038	+ .2155	− .020	+ .066	− .086
32	Rump: Right hind quarter	3	1	33.17	4.14	29.03	2.83	4.80	2.91	1.89	.167	.3973	.675	.542	.133
51	Rump: Left hind quarter	65	22	32.79	3.93	28.86	3.05	4.72	2.52	2.20	.218	.6393	.637	.579	.058
	Change	62	21	−0.38	−0.21	−0.17	+0.22	−0.08	−0.39	+0.31	+ .051	+ .2420	− .038	+ .037	− .075
33	Loin: Right hind quarter	3	1	34.46	4.41	30.05	2.82	4.97	3.05	1.92	.161	.3912	.664	.544	.120
52	Loin: Left hind quarter	65	22	32.23	3.56	28.67	2.84	4.76	2.50	2.26	.195	.6161	.605	.572	.033
	Change	62	21	−2.23	−0.85	−1.38	+0.02	−0.21	−0.55	+0.34	+ .034	+ .2249	− .059	+ .028	− .087
34	Flank: Right hand quarter	3	1	32.88	4.47	28.41	2.88	4.77	3.04	1.73	.133	.3606	.654	.560	.094
53	Flank: Left hind quarter	65	22	29.02	.280	26.22	2.75	4.35	2.33	2.02	.141	.5048	.597	.565	.032
	Change	62	21	−3.86	−1.67	−2.19	−0.13	−0.42	−0.71	+0.29	+ .008	+ .1442	− .057	+ .005	− .062

Table 35 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the fresh material.

Table 36 shows the composition of the sodium chlorid extract expressed in terms of percentages of moisture-free and fat-free material.

The data for total solids show appreciable decreases in this constituent. It will be recalled that carcasses Nos. 1 and 2, stored for 14 and 28 days, respectively, show smaller but appreciable decreases in total solids, while carcass No. 3, stored for 42 days, showed irregular changes.

Changes in the ash are in the nature of appreciable decreases, which, in large part, may be accounted for by the similar but smaller decreases in total soluble phosphorus, as will be seen if the changes in soluble phosphorus are calculated in terms of normal potassium phosphate.

Organic extractives show decreases similar to but smaller than those noted in the case of total solids.

In the acidity of the samples there are appreciable but not large increases, which would be slightly larger if correction is made for the increases in ammonia.

Table 37 shows the changes in the composition of the fat during storage.

Slight changes in the iodin numbers and refractive indices are without significance.

There are marked increases in the acidity of the kidney and the external fats and an appreciable increase in that of the intermuscular fat. Each of these increases is greater than the corresponding increase in carcass No. 3 stored for 42 days. The kidney and external fats were of very poor quality and the intermuscular fat was of fair quality.

TABLE 37.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.		Iodin number.	Refractive index 40° C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D.	*H.*					
35	Kidney fat: Right hind quarter..	3	1	40.85	1.4562	0.28	Neg.....	Normal.
54	Kidney fat: Left hind quarter....	65	22	41.93	1.4568	4.79	...do....	Strong flavor and odor.
36	Intermuscular fat: Right hind quarter.	3	1	50.44	1.4570	.28	...do....	Normal.
55	Intermuscular fat: Left hind quarter.	65	22	50.63	1.4572	1.47	...do....	Fair quality.
37	External fat: Right hind quarter.	3	1	57.53	1.4576	.23	...do....	Normal.
56	External fat: Left hind quarter...	65	22	55.89	1.4578	3.55	...do....	Strong flavor and odor; not so pronounced as No. 54.

Table 38 shows the distribution of the nitrogen and phosphorus on the basis of 100 parts of the respective constituents in the meat at the beginning of the storage period.

There are appreciable decreases in total nitrogen, to which attention has been called in connection with Table 34.

There are quite marked decreases in the total soluble nitrogen. It will be recalled that carcasses Nos. 1 and 2 also showed decreases in total soluble nitrogen during storage, carcass No. 3 having been the only one thus far that has shown an increase in total soluble nitrogen during storage.

Coagulable nitrogen shows marked decreases, which are considerably greater than those noted in case of any of the carcasses stored for shorter periods of time. Changes in noncoagulable nitrogen consist in quite marked increases, which, on the whole, are greater than those observed in any of the carcasses stored for shorter periods of time.

Proteose nitrogen shows appreciable increases, which, however, are much smaller than those observed in the cases of carcasses Nos. 2 and 3 stored for 28 and 42 days, respectively, and are approximately the same as those noted in case of carcass No. 1 stored for 14 days. These facts indicate clearly that proteoses are simply an intermediate product in the protein autolysis that takes place in beef during cold storage.

Changes in amino nitrogen are in the nature of marked increases, which are greater than those that took place in carcasses stored for shorter periods of time. These results are in conformity with the continued increase in amino nitrogen that occurred throughout the autolysis experiment.

Ammoniacal nitrogen shows appreciable increases, which are greater than those that took place in any of the previous experiments.

The decided decreases which seem to have occurred in total phosphorus are at present inexplicable.

Table 39 shows the distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus, respectively. For the most part the data for nitrogen do not demand special discussion. The changes noted indicate an increased proteolysis; amino nitrogen, in particular, constituting a larger proportion of the total nitrogen than in the carcasses stored for shorter periods of time.

Changes in insoluble phosphorus are irregular and have no apparent significance.

Soluble phosphorus shows changes which have no more significance than the equal and opposite changes in insoluble phosphorus.

The increases in the ratio of soluble inorganic phosphorus to total phosphorus are exceptionally small in comparison with the length of

TABLE 38.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period. D.	Storage period. H.	Nitrogen. Total.	Nitrogen. Soluble.	Nitrogen. Coagulable.	Nitrogen. Non-coagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Nitrogen. Ammoniacal.	Phosphorus. Total.	Phosphorus. Insoluable.	Phosphorus. Soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
31	Round: Right hind quarter	3	1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
50	Round: Left hind quarter	65	22	96.33	96.16	77.99	126.34	122.89	154.43	126.55	95.31	89.21	97.12	111.65	25.67
32	Rump: Right hind quarter	3	1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
51	Rump: Left hind quarter	65	22	99.39	98.33	86.60	116.40	130.39	160.91	129.18	92.21	85.60	94.28	106.73	43.41
33	Loin: Right hind quarter	3	1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
52	Loin: Left hind quarter	65	22	97.10	95.77	81.97	117.71	121.12	157.49	120.71	92.56	97.14	91.13	105.20	27.27
34	Flank: Right hind quarter	3	1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
53	Flank: Left hind quarter	65	22	97.87	91.19	76.64	116.76	106.01	139.99	146.67	93.90	105.29	91.17	100.93	33.12

TABLE 39.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period. D.	Storage period. H.	Nitrogen. Total.	Nitrogen. Soluble.	Nitrogen. Coagulable.	Nitrogen. Non-coagulable.	Nitrogen. Proteose.	Nitrogen. Amino.	Nitrogen. Ammoniacal.	Phosphorus. Total.	Phosphorus. Insoluable.	Phosphorus. Soluble.	Phosphorus. Soluble inorganic.	Phosphorus. Soluble organic.
31	Round: Right hind quarter	3	1	100.00	31.87	19.90	11.97	1.07	2.55	0.29	100.00	22.88	77.12	64.08	13.04
50	Round: Left hind quarter	65	22	100.00	31.82	16.11	15.71	1.36	4.09	.38	100.00	21.42	78.58	75.08	3.50
	Change	62	21	0.00	− .16	−19.03	+31.15	+27.57	+60.32	+31.48	0.00	−6.38	+1.89	+17.17	−73.16
32	Rump: Right hind quarter	3	1	100.00	32.30	19.58	12.72	1.13	2.67	.30	100.00	23.88	76.12	61.16	14.96
51	Rump: Left hind quarter	65	22	100.00	31.96	17.06	14.90	1.48	4.33	.39	100.00	22.18	77.82	70.79	7.03
	Change	62	21	0.00	−1.07	−12.87	+17.12	+31.19	+ 61.89	+30.06	0.00	−7.12	+2.24	+15.75	−53.01
33	Loin: Right hind quarter	3	1	100.00	32.81	20.13	12.68	1.06	2.58	.28	100.00	23.73	76.27	62.49	13.78
52	Loin: Left hind quarter	65	22	100.00	32.36	17.00	15.36	1.33	4.19	.35	100.00	24.91	75.09	71.04	4.05
	Change	62	21	0.00	−1.36	−15.58	+21.22	+24.74	+62.20	+24.30	0.00	+4.97	−1.55	+13.68	−70.61
34	Flank: Right hind quarter	3	1	100.00	30.79	19.63	11.16	.86	2.33	.25	100.00	19.34	80.66	69.05	11.61
53	Flank: Left hind quarter	65	22	100.00	28.69	15.37	13.32	.93	3.33	.38	100.00	21.70	78.30	74.21	4.09
	Change	62	21	0.00	−6.82	−21.69	+19.30	+8.32	+43.03	+49.75	0.00	+12.20	−2.93	+7.47	−64.77

the storage period, and when these changes are expressed in terms of percentages of the initial ratio of inorganic to total phosphorus the changes are smaller, on the whole, than those obtained in Experiment No. 1, where the storage period was but two weeks. In view of the unusually large proportion of inorganic phosphorus contained in the original material large increases were not to have been expected, and the changes that did take place should be viewed from the standpoint indicated in the discussion of the inorganic phosphorus results obtained in Experiment No. 2, where a somewhat similar condition prevailed. As the material used in this experiment was not quantitatively comparable with that used in any of the earlier experiments as regards the amount of performed inorganic phosphorus that it contained, there is no criterion by which to judge the quantitative significance of the changes in inorganic phosphorus in the present experiment.

The increments in the ratios of soluble organic to total phosphorus are small in comparison with the length of the storage period, though they constitute a decidedly high percentage of the initial ratios. Relations of the same nature have already been pointed out and discussed in connection with Experiment No. 2. For the rest, the changes in the soluble organic phosphorus have no more significance than the corresponding changes in the soluble inorganic phosphorus.

EXPERIMENT NO. 5.

HISTORY OF CARCASS.

A "grade" Shorthorn steer 3 years old, of prime quality and highly finished, was slaughtered by the usual methods and the carcass was allowed to hang 1 hour and 15 minutes on the killing floor before being run into the fore cooler. The warm carcass weighed 860 pounds. The carcass was held 19 hours in the fore cooler and 21 hours in the main cooler. The hind quarters were then cut from the carcass, carefully wrapped, and transported to the city wholesale market of the packing house, where they were held five hours in a cold-storage room having a temperature of about 38° F., and were then transported to the bureau's cold-storage rooms.

STORAGE.

The beef was unwrapped, weighed, and hung in cold-storage room No. 1 until the next day, when one quarter was prepared for analysis. The second quarter was held in cold storage for an additional period of 74 days.

The temperature of the cold-storage room ranged for the most part between 34° and 38° F. On each of two occasions, however, the temperature ran up to 41° F., and on one occasion it rose to 50° F. for a part of a day in consequence of difficulties with the refrigerating equipment. Temperature conditions were not so satisfactory as in previous experiments, and as a consequence the time that it was posssible to carry this quarter of beef in cold storage was probably shorter than it otherwise would have been. The humidity of the cold-storage room ranged from 70 to 82 per cent.

Observations as to the condition of the beef during storage were made at approximately weekly intervals, but only a few of them will be reported.

After 25 days in cold storage the beef was in good condition and showed no evidences of deterioration. At the end of 53 days in cold storage the beef was in generally good condition. There was a fairly heavy growth of mold on the inside of the flank. This part of the quarter had a rather strong odor, and in consequence of a poor circulation of air was rather damp. There was a slight growth of mold on the shank and on the exposed muscular tissue at the butt of the round. Except as noted above, the meat had no objectionable odor.

At the end of the storage period, or after 74 days in the bureau's cold-storage room, and after a total storage period of 77 days, the quarter of beef had a generally old and stale appearance. The external and kidney fat had turned dark in color and had a rather strong odor. The flank was dry and hard. There was practically no growth of mold on the meat. The beef had a rather "old" but not putrefactive odor.

A veterinary inspector familiar with the commercial handling of chilled beef pronounced the quarter of beef to be in good marketable condition, and stated that in his opinion the beef would have kept a couple of months longer in cold storage. The quarter of beef showed a shrinkage of 7.47 per cent at the end of the storage period.

QUALITY OF MEAT,

Fresh quarter, stored 70 hours.—This quarter of beef was of very high grade both as regards form and finish, and was superior to any of the quarters previously used in these experiments. It was exceedingly well covered with fat, even well down on the shank; but the covering of fat was not excessive. This quarter would have been classed as "prime" beef. The organoleptic properties of the broiled test steak were described by the judges as follows:

Mr. B.—The steak has an excellent flavor and is as tender as any of the previously examined steaks that were cut from fresh quarters of beef. The tenderloin is fairly tender; the loin portion is rather tough; and the flank end is quite tough and stringy and hard to masticate.

Mr. C.—All portions of the steak are juicy and have an excellent flavor. The tenderloin is quite tender, the loin portion is a trifle tough, and the flank end is coarse, tough, and rubbery.

Quarter of beef stored 76 days, 21 hours.—When the quarter of beef was cut up preparatory to analysis the cut surface at the butt of the round was found to have a bright-red color, but the color was not as bright as that of the corresponding fresh quarter of beef. Where the surface of the meat had been protected by a fatty covering there was no darkening of the muscular tissue at the surface, but where the cut surface had been exposed to the air, e. g., at the butt of the round, there was a dark brown zone extending inward about one-eighth of an inch from the surface. The odor from the cut surface of the meat was sweet, but perhaps a trifle "gamey."

When the loin was cut into the short loin and the sirloin butt the freshly cut surfaces had a bright-red color and a sweet but "gamey" odor. There was no darkening of the musculature at the surface, which was well covered with fat. A slice about three-fourths of an inch thick was cut from the tip end of the loin, which had been exposed during storage and had become dry and dark colored, and the freshly cut surface thus exposed was dark red in color and had a strong "gamey" but not putrefactive odor. When the meat was cut up for analysis there were no evidences of putrefaction, and the meat appeared to be in perfectly sound condition.

The kidney fat was in poor condition, being discolored, and there was a considerable growth of mold scattered throughout the mass. The external fat was quite dark in color and had a strong, sour, and rather penetrating odor.

The raw test steak had a bright-red color and an attractive appearance and a sweet but a trifle "gamey" odor. The opinions rendered by the judges as to the quality of the broiled steak are as follows:

Mr. A.—The tenderloin is quite tender, rather dry, and lacking in flavor. The loin portion is quite tender but even drier than the tenderloin, and is lacking in flavor. The flank end is fairly tender but quite dry and has an "old" flavor. The fat has an "old" taste.

Mr. B.—On the whole the steak is quite tender but rather dry. It has a rather "old" but not disagreeable flavor.

Mr. C.—The tenderloin and loin portions of the steak are very tender, juicy, and palatable. The flank end is quite tender and fairly palatable. On the whole this steak is superior to any of the other steaks which have been tested thus far.

CHEMICAL EXAMINATION CARCASS NO. 5.

Tables 40 to 46, inclusive, show the changes that took place in the composition of carcass No. 5 during 74 days in cold storage.

Table 40 shows the composition of the meat expressed in terms of percentages of the original material.

Table 41 shows the composition of the meat expressed in terms of percentages of the moisture-free and fat-free material.

The data indicate appreciable decreases in the moisture content of the meat during storage, the decreases being greater than those that occurred in any of the carcasses previously examined.

There are slight apparent decreases in the ash which are accompanied by decreases in total phosphorus.

Changes in nitrogen and phosphorus compounds will be discussed in connection with Tables 45 and 46.

TABLE 40.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D. H.								
44	Round: Left hind quarter...	2 22	73.15	3.15	1.08	3.45	0.0101	0.206	0.149	0.057
69	Round: Right hind quarter.	76 21	71.27	3.30	1.11	3.58	.0133	.206	.163	.043
45	Rump: Left hind quarter...	2 22	72.33	4.87	1.05	3.32	.0094	.195	.153	.042
70	Rump: Right hind quarter.	76 21	69.90	5.89	1.06	3.47	.0128	.198	.152	.046
46	Loin: Left hind quarter.....	2 22	72.06	5.34	1.03	3.36	.0083	.190	.144	.046
71	Loin: Right hind quarter...	76 21	69.63	5.80	1.08	3.44	.0163	.196	.154	.042

TABLE 41.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free material.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
44	Round: Left hind quarter...	2 22	75.53	4.54	14.54	0.0428	0.870	0.627	0.243
69	Round: Right hind quarter..	76 21	73.70	4.37	14.08	.0522	.808	.641	.167
	Change..................	73 23	−1.83	−0.17	−0.46	+.0094	−.062	+.014	−.076
45	Rump: Left hind quarter...	2 22	76.03	4.61	14.54	.0413	.853	.670	.183
70	Rump: Right hind quarter..	76 21	74.27	4.38	14.33	.0528	.816	.627	.189
	Change..................	73 23	−1.76	−0.23	−0.21	+.0115	−.037	+.043	+.006
46	Loin: Right hind quarter....	2 22	76.13	4.56	14.85	.0366	.839	.639	.200
71	Loin: Left hind quarter.....	76 21	73.92	4.38	14.00	.0665	.797	.626	.171
	Change..................	73 23	−2.21	−0.18	−0.85	+.0299	−.042	−.013	−.029

Table 42 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the original material.

Table 43 shows the composition of the sodium chlorid extract of the meat expressed in terms of percentages of the moisture-free and fat-free material.

Changes in the total solids are irregular, but on the whole appreciable increases in this constituent have occurred. It is of interest to note that this is the first experiment in which there has been an increase in the total soluble solids of the meat during storage, previous experiments in which the meat had been stored for shorter periods of time having shown decreases in this constituent.

TABLE 42.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
44	Round: Left hind quarter	2 22	6.72	0.86	5.86	0.76	0.899	0.467	0.432	0.022	0.0935	0.149	0.103	0.046
69	Round: Right hind quarter	76 21	7.13	.63	6.50	.88	1.00	.401	.599	.066	.1987	.163	.144	.019
45	Rump: Left hind quarter	2 22	6.65	.82	5.83	.73	.894	.477	.417	.027	.0955	.153	.098	.055
70	Rump: Right hind quarter	76 21	7.32	.62	6.70	.88	1.02	.422	.598	.046	.1970	.152	.135	.017
46	Loin: Left hind quarter	2 22	6.79	.81	5.98	.69	.915	.513	.402	.026	.0908	.144	.096	.048
71	Loin: Right hind quarter	76 21	7.87	.94	6.93	.87	1.05	.429	.621	.048	.2248	.154	.138	.016

TABLE 43.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
44	Round: Left hind quarter	2 22	28.36	3.63	24.73	3.21	3.79	1.97	1.82	0.094	0.3945	0.627	0.433	0.194
69	Round: Right hind quarter	76 21	28.03	2.48	25.55	3.44	3.93	1.58	2.35	.258	.7811	.641	.565	.076
	Change	73 23	−0.33	−1.15	+0.82	+0.23	+0.14	−0.39	+0.53	+.164	+.3866	+.014	+.132	−.118
45	Rump: Left hind quarter	2 22	29.15	3.58	25.57	3.20	3.92	2.09	1.83	.119	.4188	.670	.430	.240
70	Rump: Right hind quarter	76 21	30.22	2.56	27.66	3.61	4.21	1.75	2.46	.189	.8134	.627	.559	.068
	Change	73 23	+1.07	−1.02	+2.09	+0.41	+0.29	−0.34	+0.63	+.070	+.3946	−.043	+.129	−.172
46	Loin: Left hind quarter	2 22	30.03	3.56	26.47	3.03	4.05	2.27	1.78	.116	.4017	.639	.425	.214
71	Loin: Right hind quarter	76 21	32.03	3.81	28.22	3.54	4.25	1.75	2.50	.195	.9148	.626	.563	.063
	Change	73 23	+2.00	+0.25	+1.75	+0.51	+0.20	−0.52	+0.72	+.079	+.5131	−.013	+.138	−.151

There are marked apparent decreases in the ash content of the round and rump, and a slight gain in that of the loin during storage. These large decreases must be regarded with suspicion.

On account of the suspicious character of the data for ash, positive value can not be assigned to those for organic extractives.

Increases in acidity are fairly marked and are greater than those which took place in any of the previous cold-storage experiments.

Table 44 shows the changes in the composition of the fat that took place during storage. The most important changes were very marked increases in the acidity of the external and the kidney fats, and an appreciable increase in that of the intermuscular fat. The increase in the acidity of the kidney fat was nearly twice as great, and that of the external fat was three times as great, as the corresponding increases in acidity in the preceding experiment. The increase in the acidity of the intermuscular fat was only slightly greater than in the preceding experiment. The kidney and external fats were of very poor quality, while the intermuscular fat was of fair quality.

TABLE 44.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40°C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. *H.*					
47	Kidney fat: Left hind quarter....	2 22	39.85	1.4562	0.34	Neg.....	Normal.
72	Kidney fat: Right hind quarter..	76 21	38.21	1.4555	8.04	...do....	Dark yellow; strong, sour odor; very strong flavor.
48	Intermuscular fat: Left hind quarter.	2 22	44.70	1.4566	.28	...do....	Normal.
73	Intermuscular fat: Right hind quarter.	76 21	44.63	1.4562	1.70	...do....	Normal odor; comparatively sweet flavor.
49	External fat: Left hind quarter...	2 22	50.76	1.4570	.34	...do....	Normal.
74	External fat: Right hind quarter.	76 21	50.21	1.4560	10.86	...do....	Dark yellow; strong, sour odor; strong disagreeable flavor.

Table 45 shows the distribution of the nitrogen and the phosphorus upon the basis of 100 parts of the respective constituents in the meat at the beginning of the storage period.

There are appreciable decreases in total nitrogen that range from 5.72 per cent in the case of the loin to 1.44 per cent in the case of the rump. These data confirm the losses in total nitrogen that were observed in carcasses Nos. 2, 3, and 4; carcass No. 1 alone having shown slight apparent gains. The regular occurrence of a decrease in the total nitrogen content of the lean meat from 4 carcasses stored for periods ranging from 28 to 74 days would appear to indicate an actual loss of nitrogen from the meat during storage.

Fairly marked increases in the amount of total soluble nitrogen present in the meat have occurred during this storage period. These are the first appreciable increases in total soluble nitrogen that have taken place in any of the carcasses examined thus far. These data are in keeping with the previously noted increases in total solids in this experiment.

Coagulable nitrogen shows appreciable decreases, which are practically the same as those noted in the previous experiments. As has been previously noted, the data for coaguable nitrogen show merely the variations in the actual reserve amount of this constituent, and do not indicate the true extent of the transformation of coagulable proteins into noncoagulable forms, inasmuch as the supply of coagulable protein is being replenished from the insoluble protein at the same time as the coagulable protein is being transformed into noncoagulable compounds. The true extent of the change of coagulable protein into noncoagulable forms is shown in the data for noncoagulable nitrogen.

Increases in noncoagulable nitrogen, which range from 29.12 to 40.45 per cent, are much greater than the increases that took place in this constituent in the previous experiment.

Changes in proteose nitrogen are in the nature of increases, which are greater than those that took place in any of the previous experiments except Experiment No. 2.

The amino nitrogen almost doubled in the round and rump, and more than doubled in the loin during the storage period. The increases are larger than any corresponding increases that occurred in this constituent during the shorter periods of the previous experiments. The results are in continued conformity with the results of the autolysis experiment.

Ammoniacal nitrogen increased in each of the cuts analyzed. The increases in the round and rump, however, were not as great as the corresponding increases in Experiment No. 4, a fact which stands in no connection with the amounts of preformed ammonia in the material, but which must be accounted as a distinct exception to the rule that seems to have applied in most of these experiments. The increase in the loin, on the other hand, was the largest that had yet been observed in this constituent.

Changes in total phosphorus consisted in quite marked apparent decreases, the significance of which is not clear.

Table 46 shows the distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus.

Soluble nitrogen makes up a smaller proportion of the total nitrogen of the fresh quarter of this carcass than it made in case of any fresh quarter previously examined.

Coagulable nitrogen forms a smaller proportion of the total nitrogen of the meat, both at the beginning and at the end of the storage

TABLE 45.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.		Nitrogen.							Phosphorus.				
				Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D.	*H.*												
44	Round: Left hind quarter	2	22	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
69	Round: Right hind quarter	76	21	96.84	103.69	80.20	129.12	274.47	198.00	121.96	92.90	69.03	102.15	130.37	39.03
45	Rump: Left hind quarter	2	22	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
70	Rump: Right hind quarter	76	21	98.56	107.40	83.73	134.43	158.82	194.22	127.85	95.65	102.72	93.71	129.83	28.69
46	Loin: Left hind quarter	2	22	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
71	Loin: Right hind quarter	76	21	94.28	104.94	77.09	140.45	168.10	227.70	181.69	95.06	85.81	97.96	132.47	29.42

TABLE 46.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.		Nitrogen.							Phosphorus.				
				Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D.	*H.*												
44	Round: Left hind quarter	2	22	100.00	26.07	13.55	12.52	0.647	2.71	0.294	100.00	27.94	72.06	49.79	22.27
69	Round: Right hind quarter	76	21	100.00	27.91	11.22	16.69	1.832	5.55	.371	100.00	20.76	79.24	69.89	9.35
	Change	73	23	0.00	+ 7.08	−17.18	+33.34	+183.43	+104.47	+25.96	0.00	− 25.70	+9.96	+40.37	−58.02
45	Rump: Left hind quarter	2	22	100.00	26.96	14.37	12.59	.818	2.88	.284	100.00	21.53	78.47	50.44	28.03
70	Rump: Right hind quarter	76	21	100.00	29.38	12.21	17.17	1.319	5.68	.368	100.00	23.11	76.89	68.48	8.41
	Change	73	23	0.00	+ 8.97	−15.04	+36.40	+61.15	+97.07	+29.62	0.00	+ 7.34	−2.01	+35.77	−70.00
46	Loin: Left hind quarter	2	22	100.00	27.27	15.29	11.98	.731	2.71	.246	100.00	23.86	76.14	50.65	25.49
71	Loin: Right hind quarter	76	21	100.00	30.36	12.50	17.86	1.393	6.53	.475	100.00	21.54	78.46	70.57	7.89
	Change	73	23	0.00	+11.31	−18.23	+48.97	+78.31	+141.56	+92.97	0.00	− 9.72	+3.05	+39.33	−69.05

period, than in the case of the corresponding quarter of any of the other carcasses examined to date.

Changes in insoluble phosphorus are irregular and of undetermined significance.

Total soluble phosphorus underwent irregular changes that have no determined significance.

The increases that took place in the soluble inorganic phosphorus content of the meat during the storage period of 74 days are greater for each portion of the carcass analyzed than any corresponding increase obtained in the earlier experiments of this series. The material used for this experiment is directly comparable, in regard to the amount of inorganic phosphorus that it originally contained, to the material that was used in Experiments Nos. 1 and 3. The increases noted are therefore in continued accord with the results of the autolysis experiment.

Changes in the ratios of organic to total phosphorus possess no more significance than do the corresponding changes in the inorganic phosphorus ratios.

EXPERIMENT NO. 6.

HISTORY OF CARCASS.

A "grade" Shorthorn steer 3½ years old, of good conformation but only fairly well finished, was slaughtered in the usual manner, and the carcass after hanging for 1 hour on the killing floor was run into the fore cooler. The carcass was held 14½ hours in the fore cooler, having a temperature ranging from 34° to 41° F., and 50 hours in the main cooler, having a temperature of 30° F. The humidity of the fore cooler was 100 per cent of saturation at the time the carcass was placed in storage. After storage for 64½ hours in the packing-house coolers, the hind quarters were cut from the carcass, and one quarter was carefully wrapped and transported to the bureau's cold-storage room, where it was promptly prepared for analysis. The total storage period for this quarter of beef was 66 hours.

STORAGE.

The second quarter of beef was held in storage in the main cooler of the packing house in order to determine how long beef could be held in cold storage under commercial conditions such as existed in this cooler, as compared with the length of time that it could be held in storage in the bureau's experimental cold-storage room where the other quarters of beef had been held in storage. This packing-house cooler, which can accommodate about 250 carcasses of beef, was kept nearly filled with beef during the course of the experiment.

The temperature of the cooler ranged from 28° to 32° F. during the storage period, but for the most part remained at about 32° F., while the humidity varied from 92 to 95 per cent of saturation. The humidity appears relatively high, yet the cooler was in apparently dry condition throughout the course of the experiment. There was no condensation of moisture on the walls or ceiling, and the surfaces of the carcasses were dry and firm. The circulation of air appeared to be excellent. The high humidity, apparently, was due to the continuous evaporation of moisture from the carcasses of beef held in cold storage.

After 20 days of storage the quarter of beef was in excellent condition and no growth of mold had appeared on the meat. At the end of 40 days of storage the beef was in fairly good condition. There was a light growth of mold over most of the quarter except on the top of the loin, where there was a heavy covering of fat. The growth of mold was heaviest on the cut end of the loin, on the exposed flank muscles, and on the under side of the loin. There was a slightly sour odor at the cut end of the loin. The meat was still in good marketable condition and would have needed but little trimming. After storage for 55 days the beef was in such condition that it was deemed inadvisable to carry it longer in cold storage. There was a heavy growth of mold over most of the quarter, except on the upper side of the loin, where there was a heavy covering of fat. There was a slightly "off" odor at the cut end of the loin, but practically no odor from the rest of the quarter. It showed a shrinkage of 3.27 per cent during storage. The quarter of beef was carefully wrapped and transported to the bureau's cold-storage room, where it was held a day longer at a temperature ranging from 34° to 48° F., after which it was prepared for analysis.

QUALITY OF MEAT.

Quarter of beef stored 66 hours.—This quarter of beef was of fair quality and finish. The loin was well covered with fat, while the round, particularly about the shank, was only fairly well covered. There was a good but not an excessive deposit of kidney fat. The broiled test steak cut from this quarter was described by the judges as follows:

Mr. A.—The tenderloin is fairly tender, the loin portion is quite tough, and the flank end is very tough. The flavor of the steak is very good.

Mr. B.—The flavor of the steak is excellent. For a fresh steak it is fairly tender. The tenderloin is the most tender and the flank end the least so.

Mr. C.—The tenderloin is comparatively tender, the loin portion rather tough, and the flank end very tough and rubbery. The steak is juicy and has an excellent flavor.

Quarter of beef stored 56 days, 18 hours.—When the quarter of beef was cut up for analysis the cut surface at the butt of the round was found to have a bright-red color. Where the surface of the meat had been but thinly covered with fat, and where the muscular tissue had been exposed, there was a dark-brown zone extending to a depth of from one-sixteenth to one-quarter of an inch from the surface. The loin was in good condition and showed no evidences of putrefaction.

The raw steak showed no evidences of putrefaction. The opinions rendered by the judges as to the organoleptic properties of the broiled steak are as follows:

Mr. A.—The tenderloin is very tender and is one of the best pieces of meat which we have tested. The loin portion is comparatively tender and has an excellent flavor. The flank end is somewhat tough, but is palatable. The steak has an excellent flavor.

Mr. B.—On the whole the steak is very tender, perhaps the most tender steak of the series. The flavor is not so good as that of the fresh steak, particularly at the outer portion, which has an "off" flavor. The flavor of the fat has deteriorated.

Mr. C.—The steak is tender and juicy, but lacking in flavor. The tenderloin is very tender and the loin portion is fairly tender. The flank end is comparatively tender, more so, in fact, than the same portion of any of the steaks previously tested.

CHEMICAL EXAMINATION OF CARCASS NO. 6.

Tables 47 to 53, inclusive, show the changes which took place in the composition of carcass No. 6 during 54 days in cold storage.

Table 47 shows the composition of the meat expressed in terms of percentages of the original material.

Table 48 shows the composition of the meat expressed in terms of percentages of the moisture-free and fat-free material.

There are slight decreases in the moisture content of the meat, and the changes in the percentage of ash present are insignificant.

Changes in nitrogen and phosphorus compounds will be considered in connection with Tables 52 and 53.

TABLE 47.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D. H.								
82	Round: left hind quarter....	2 18	74.46	3.52	1.05	3.31	0.0097	0.195	0.152	0.043
94	Round: Right hind quarter.	56 18	73.80	3.61	1.08	3.35	.0104	.197	.153	.044
83	Rump: Left hind quarter...	2 18	72.71	5.71	1.00	3.16	.0094	.191	.144	.047
95	Rump: Right hind quarter.	56 18	72.64	5.79	1.03	3.20	.0103	.183	.144	.039
84	Loin: Left hind quarter.....	2 18	70.93	8.16	0.97	3.19	.0086	.183	.139	.044
96	Loin: Right hind quarter...	56 18	70.75	7.43	1.00	3.25	.0104	.177	.135	.042

TABLE 48.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
82	Round: Left hind quarter...	2 18	77.17	4.75	15.00	0.0439	0.883	0.688	0.195
94	Round: Right hind quarter.	56 18	76.56	4.76	14.83	.0462	.871	.677	.194
	Change................	54	− 0.61	+ 0.01	− 0.17	+ .0023	− .012	− .011	− .001
83	Rump: Left hind quarter...	2 18	77.12	4.61	14.64	.0434	.885	.669	.216
95	Rump: Right hind quarter..	56 18	77.11	4.78	14.84	.0477	.848	.666	.182
	Change................	54	− 0.01	+ 0.17	+ 0.20	+ .0043	− .037	− .003	− .034
84	Loin: Left hind quarter.....	2 18	77.23	4.64	15.24	.0410	.876	.663	.213
96	Loin: Right hind quarter....	56 18	76.42	4.56	14.89	.0478	.810	.619	.191
	Change................	54	− 0.81	− 0.08	− 0.35	+ .0068	− .066	− .044	− .022

Table 49 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the original material.

Table 50 shows the composition of the meat expressed in terms of percentages of moisture-free and fat-free material.

The amount of total soluble solids present in the meat has increased considerably during the storage period. It is of interest to note in this connection that only one other carcass that has been examined thus far, viz, carcass No. 5, stored for 74 days, has shown appreciable increases in total soluble solids during storage. The increases that took place in this constituent in carcass No. 6 are greater than those which took place in carcass No. 5.

There are appreciable increases in ash of extract, the significance of which is not yet apparent.

Increases are observed in organic extractives that are similar to, but smaller than, the increases in total soluble solids.

Changes in the acidity of the meat during storage are irregular and without significance.

Table 51 shows the changes that took place in the composition of the fat during storage. The appreciable changes that appear to have taken place in the iodin absorption numbers of the samples are probably due to irregularities in the sampling of the fatty tissues rather than to actual changes in the iodin absorptive values of the fats.

The principal changes that took place in the fats during storage were fairly marked increases in the acidity of the kidney and external fats, and an appreciable increase in the acidity of the intermuscular fat. On the whole the increases in the acidity of the fats of this carcass are approximately equal to those that took place in this constituent in carcass No. 4, which was stored for 63 days in the bureau's cold-storage room.

TABLE 49.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.				Phosphorus.			
		D.	H.					Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
82	Round: Left hind quarter	2	18	6.21	0.76	5.45	0.70	0.870	0.474	0.396	0.018	0.0820	0.152	0.099	0.053
94	Round: Right hind quarter	56	18	6.62	.92	5.70	.71	.908	.427	.481	.059	.1063	.153	.127	.026
83	Rump: Left hind quarter	2	18	6.40	.87	5.53	.65	.860	.472	.388	.022	.0799	.144	.094	.050
95	Rump: Right hind quarter	56	18	6.83	.93	5.90	.71	.913	.470	.443	.073	.1097	.144	.119	.025
84	Loin: Left hind quarter	2	18	6.29	.82	5.47	.64	.870	.502	.368	.013	.0771	.139	.089	.050
96	Loin: Right hind quarter	56	18	6.76	.88	5.88	.56	.938	.484	.454	.060	.0964	.135	.116	.019

TABLE 50.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.		Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.				Phosphorus.			
		D.	H.					Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
82	Round: Left hind quarter	2	18	28.19	3.45	24.74	3.18	3.95	2.15	1.80	0.082	0.3724	0.688	0.451	0.237
94	Round: Right hind quarter	56	18	29.28	4.07	25.21	3.14	4.02	1.89	2.13	.264	.4706	.677	.564	.113
	Change	54		+1.09	+0.62	+0.47	−0.04	+0.07	−0.26	+0.33	+.182	+.0982	−.011	+.113	−.124
83	Rump: Left hind quarter	2	18	29.66	4.03	25.63	2.99	3.99	2.19	1.80	.100	.3703	.669	.433	.236
95	Rump: Right hind quarter	56	18	31.64	4.32	27.32	3.27	4.24	2.18	2.06	.338	.5087	.666	.552	.114
	Change	54		+1.98	+0.29	+1.69	+0.28	+0.25	−0.01	+0.26	+.238	+.1384	−.003	+.119	−.122
84	Loin: Left hind quarter	2	18	30.10	3.90	26.20	3.06	4.16	2.40	1.76	.062	.3688	.663	.423	.240
96	Loin: Right hind quarter	56	18	30.97	4.04	26.93	2.54	4.30	2.22	2.08	.277	.4417	.619	.532	.087
	Change	54		+0.87	+0.14	+0.73	−0.52	+0.14	−0.18	+0.32	+.215	+.0729	−.044	+.109	−.153

TABLE 51.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40°C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. H.					
85	Kidney fat: Left hind quarter....	2 18	41.65	1.4560	0.34	Neg.....	Normal.
97	Kidney fat: Right hind quarter..	56 18	39.38	1.4560	3.10	...do....	Do.
86	Intermuscular fat: Left hind quarter.	2 18	48.91	1.4570	.28	...do....	Do.
98	Intermuscular fat: Right hind quarter.	56 18	49.42	1.4570	1.24	...do....	Slight meaty odor and flavor.
87	External fat: Left hind quarter...	2 18	53.60	1.4575	.39	...do....	Normal.
99	External fat: Right hind quarter..	56 18	56.75	1.4575	4.29	...do....	Do.

Table 52 shows the distribution of nitrogen and phosphorus upon the basis of 100 parts of the respective constituents in the meat at the beginning of the storage period.

Changes in total nitrogen are slight and irregular and are without significance.

Total soluble nitrogen shows fairly marked increases. This is the third experiment of this series where there has been an appreciable increase in the total soluble nitrogen in the meat during storage; the others have been Experiment No. 3, where the storage period was 44 days, and Experiment No. 5, where the storage period amounted to 74 days.

The changes in coagulable nitrogen consist in appreciable decreases, which are approximately equal to those that took place in carcass No. 1, stored for 14 days, but which are much smaller than those observed in carcasses Nos. 2 and 3, stored for 28 and 42 days, respectively.

Changes in noncoagulable nitrogen represent the true extent of the change of coagulable proteins into noncoagulable forms. Fairly marked increases are noted in this constituent, these increases being approximately equal to those observed in case of carcass No. 3, which had been stored for 42 days in the bureau's cold-storage room.

Proteose nitrogen shows very large relative increases, which are larger than those that took place in this constituent in any of the previous experiments of this series.

The increases in the amino nitrogen that occurred during this experiment are smaller throughout than the corresponding increases obtained in Experiment No. 3, where the storage period was 42 days in length. This is the first instance in this series of experiments in which the amino nitrogen has failed to show a continued increase when the cold-storage period was lengthened. This fact is probably due to the changed conditions of storage.

The average increase in ammoniacal nitrogen in this experiment is less than the average increase in Experiment No. 2, where the storage

TABLE 52.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluable.	Soluble.	Soluble inorganic.	Soluble organic.
		D. *H.*												
82	Round: Left hind quarter	2 18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
94	Round: Right hind quarter	56 18	98.87	101.77	87.91	118.33	321.95	126.37	105.24	98.61	99.28	98.41	125.22	47.51
83	Rump: Left hind quarter	2 18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
95	Rump: Right hind quarter	56 18	101.37	106.27	99.54	114.44	338.00	137.38	109.91	95.78	84.13	99.55	127.34	48.36
84	Loin: Left hind quarter	2 18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
96	Loin: Right hind quarter	56 18	97.71	103.37	92.50	118.18	446.77	119.77	116.59	92.42	89.55	93.34	125.53	36.37

TABLE 53.—*Distribution of nitrogen and phosphorus, expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluable.	Soluble.	Soluble inorganic.	Soluble organic.
		D. *H.*												
82	Round: Left hind quarter	2 18	100.00	26.33	14.33	12.00	0.55	2.48	0.29	100.00	22.10	77.90	51.03	26.87
94	Round: Right hind quarter	56 18	100.00	27.11	12.74	14.37	1.78	3.17	.31	100.00	22.26	77.74	64.80	12.94
	Change	54	0.00	+2.94	−11.09	19.69	+225.64	+27.82	+ 6.49	0.00	+ 0.72	−0.20	+26.98	−51.84
83	Rump: Left hind quarter	2 18	100.00	27.25	14.96	12.29	0.68	2.53	.30	100.00	24.48	75.52	48.95	26.57
95	Rump: Right hind quarter	56 18	100.00	28.57	14.69	13.88	2.28	3.43	.32	100.00	21.50	78.50	65.07	13.43
	Change	54	0.00	+4.83	− 1.80	+12.90	+233.44	+35.52	+ 8.48	0.00	−12.17	+3.95	+32.93	−49.45
84	Loin: Left hind quarter	2 18	100.00	27.30	15.75	11.55	0.41	2.42	.27	100.00	24.36	75.64	48.33	27.31
96	Loin: Right hind quarter	56 18	100.00	28.88	14.91	13.97	1.86	2.97	.32	100.00	23.61	76.39	65.65	10.74
	Change	54	0.00	+5.80	− 5.33	+20.95	+357.28	+22.58	+19.18	0.00	− 3.08	+0.99	+35.84	−60.67

period was but half as long; while each increase is less than the corresponding increase in Experiment No. 3, where the storage period was but three-fourths as long, and where the preformed ammonia was present in the original material in about the same quantity as in the present experiment.

Each portion of the stored quarter contained less total phosphorus than the corresponding portion of the fresh quarter. The significance of these apparent decreases is far from being clear.

Table 53 shows the distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus.

The data for nitrogen do not demand special discussion.

Changes in insoluble phosphorus are of the usual irregular nature and their significance has not been established.

The changes in soluble inorganic phosphorus are in the nature of distinct increases. As regards the amount of preformed inorganic phosphorus that it contained, the fresh material is comparable to that used for Experiments Nos. 1 and 3. By comparing the increases in the inorganic phosphorus ratio in the same three experiments it is found that the increases during the 54-day storage period of the present experiment are greater, on the whole, than the corresponding increases effected by the shorter periods of storage of Experiments Nos. 1 and 3, the only exception being that the change in the round in this experiment is somewhat less than the corresponding change in Experiment No. 3. On the whole, the results are in conformity with those obtained in the autolysis experiment.

Changes in soluble organic phosphorus are of less significance than the corresponding changes in inorganic phosphorus.

EXPERIMENT NO. 7.

HISTORY OF CARCASS.

A "grade" Shorthorn steer 4 years old, rather rough in conformation and only fairly well finished, was slaughtered in the usual manner. The carcass was allowed to hang 1 hour on the killing floor, after which it was run into the fore cooler, where it was held 16 hours, and then into the main cooler, where it was held 51 hours at 30° F. The humidity of the fore cooler was 93 per cent and that of the main cooler 92 per cent of saturation. The weight of the warm carcass was 814 pounds. After storage in the packing-house coolers for a total period of 67 hours, the hind quarters were cut from the carcass, carefully wrapped, and transported to the bureau's cold-storage rooms, where one hind quarter was immediately prepared for analysis while the other was placed in cold-storage room No. 1, where it was held in storage.

STORAGE.

The second quarter of beef was held in cold storage for an additional period of 177 days. The temperature of cold-storage room No. 1 remained fairly uniform, ranging between 32° and 36° F. during the larger part of the time. On a few occasions the temperature ran up to from 39° to 48° F. for a few hours at a time, in consequence of difficulties that were experienced with the refrigerating equipment, which finally necessitated the bringing of the experiment to a close. It is not considered that the rises in temperature that have been noted affected the value of the experiment appreciably; although the meat could have been held in cold storage for some time longer had these difficulties not been encountered. The humidity of the cold-storage room varied from 70 to 84 per cent of saturation. The following are a few of the observations that were made concerning the condition of the beef during storage:

After it had been 48 days in cold storage the quarter of beef was in generally good condition. The exposed flank and shank muscles had become darker in color and rather hard and dry in texture. There was a slight growth of mold on the cut muscular surfaces at the butt of the round and the tip of the loin.

At the end of 98 days of cold storage the beef was still in good condition. The color of the fat had changed from an original light yellow to a grayish white. There was a rather heavy growth of mold on the inside of the flank and lighter growths on the tip of the loin and on the exposed muscular tissue at the butt of the round. A slight odor was given off from the exposed, cut, muscular surfaces, but none was apparent from other parts of the quarter.

At the close of the storage period, or after a total period of 180 days of cold storage, the quarter of beef had a badly desiccated appearance, the flank being as hard as a board, and the muscles at the shank being hard, shrunken, and dark-brown in color. There was a slight growth of mold on the flank, on the tip of the loin, and on the exposed muscles at the butt of the round. The fat had become very dark in color. Although there were no apparent evidences of putrefaction, the quarter of beef was considered not to be in good marketable condition on account of the badly dried out condition of the meat.

The beef showed a shrinkage of 10 per cent during storage.

QUALITY OF MEAT.

Quarter of beef stored 68 hours.—This quarter of beef was of only fair quality, being rather rough in form and very unevenly covered with fat. There was a heavy covering of fat on the top of the loin, while the round was poorly covered. The organoleptic properties of the broiled test steak were described by the respective judges as follows:

Mr. A.—The tenderloin is fairly tender, the loin portion rather tough, and the flank end very tough. All portions of the steak have a good flavor.

Mr. B.—As a whole the steak has a good flavor and is fairly tender. The different portions follow the usual order as regards tenderness.

Mr. C.—The tenderloin and loin portions of the steak are comparatively tender, while the flank end is rather tough. The steak is juicy and has a good flavor.

Quarter of beef stored 179 days, 20 hours.—When the quarter of beef was cut up for analysis, the cut surface at the butt of the round had a normal red color. Where the surface of the meat was covered with fat, the red color extended to the fat; but where the muscles were exposed to the air, there was a dark-brown zone extending inward to a depth of about a quarter of an inch from the surface. The odor from the cut surface was a trifle "old" and somewhat acrid, but there was no odor of putrefaction. When the loin was cut up, the freshly cut surfaces had about the same appearance and odor as had the cut surface of the round. The kidney and external fat had a strong and rather rancid odor. The opinions of the judges as to the organoleptic properties of the broiled test steak were as follows:

Mr. A.—The loin portion is rather dry and has an "old" and rather unpleasant flavor. The flank portion is tougher than the loin and has an "old" flavor.

Mr. C.—On the whole the steak is comparatively dry and tough. The flavor is "old" and a trifle unpleasant. The quality of this steak is not nearly so good as that of steaks previously tested which had been cut from quarters of beef that had been held in cold storage for a few weeks. This steak may be classed as edible, but not palatable. No ill effects were suffered from eating the meat.

CHEMICAL EXAMINATION OF CARCASS NO. 7.

Tables 54 to 60, inclusive, show the changes which took place in the composition of carcass No. 7 during 177 days in cold storage.

Table 54 shows the composition of the meat expressed in terms of percentages of the original material.

TABLE 54.—*Composition expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Moisture.	Fat.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
								Total.	Soluble.	Insoluble.
		D. H.								
88	Round: Left hind quarter...	2 20	73.59	3.73	1.07	3.42	0.0093	0.201	0.157	0.044
114	Round: Right hind quarter..	179 20	70.91	4.66	1.13	3.49	.0196	.203	.163	.040
89	Rump: Left hind quarter...	2 20	71.61	6.32	1.01	3.26	.0091	.194	.145	.049
115	Rump: Right hind quarter..	179 20	70.36	5.77	1.08	3.49	.0205	.190	.154	.036
90	Loin: Left hind quarter.....	2 20	69.06	9.01	.98	3.23	.0079	.183	.144	.039
116	Loin: Right hind quarter...	179 20	69.80	6.19	1.09	3.35	.0187	.185	.144	.041

Table 55 shows the composition of the meat expressed in terms of percentages of the moisture-free and fat-free material.

The decreases in the moisture content of the meat during storage are greater than those that took place in any of the other carcasses of this series during shorter periods of storage, excepting in case of carcass No. 5 stored for 76 days.

Slight irregular changes in the ash content of the meat have no significance.

TABLE 55.—*Composition expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Moisture, fat-free basis.	Ash.	Total nitrogen.	Ammoniacal nitrogen.	Phosphorus.		
							Total.	Soluble.	Insoluble.
		D. H.							
88	Round: Left hind quarter...	2 20	76.45	4.72	15.07	0.0410	0.888	0.693	0.195
114	Round: Right hind quarter..	179 20	74.37	4.62	14.28	.0805	.832	.665	.167
	Change..................	177	− 2.08	− 0.10	− 0.79	+ .0395	− .056	− .027	− .028
89	Rump: Left hind quarter...	2 20	76.44	4.56	14.75	.0411	.878	.656	.222
115	Rump: Right hind quarter..	179 20	74.66	4.52	14.62	.0857	.794	.644	.150
	Change..................	177	− 1.78	− 0.04	− 0.13	+ .0446	− .084	− .011	− .072
90	Loin: Left hind quarter.....	2 20	75.89	4.47	14.70	.0361	.836	.658	.178
116	Loin: Right hind quarter....	179 20	74.41	4.54	13.96	.0780	.769	.599	.170
	Change..................	177	− 1.48	+ 0.07	− 0.74	+ .0419	− .066	− .059	− .008

Table 56 shows the composition of the 0.9 per cent sodium chlorid extract of the meat expressed in terms of percentages of the original material.

Table 57 shows the composition of the sodium chlorid extract of the meat expressed in terms of percentages of the moisture-free and fat-free material.

The amount of total soluble solids present in the meat increased considerably during storage, the increase being greater than that which took place in any of the previous experiments of this series. Similar changes are noted in the organic extractives.

Changes in acidity are irregular and comparatively small and are without significance.

Table 58 shows the changes which took place in the composition of the fat during storage.

Appreciable decreases have taken place in the refractive indices of the samples, which are in harmony with the large increases in the amount of free acid present in the samples.

Large increases have taken place in the acidity of the kidney and external fats, the increases amounting to 10.04 and 9.48 per cent, respectively. These increases in acidity are greater than those that took place in these fats in any of the previous experiments of this series, except Experiment No. 5, where the increase amounted to

TABLE 56.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of fresh material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
88	Round: Left hind quarter	2 20	6.80	0.94	5.86	0.72	0.943	0.520	0.423	0.038	0.0842	0.157	0.110	0.047
114	Round: Right hind quarter	179 20	8.22	1.05	7.17	.80	1.13	.475	.655	.068	.2253	.163	.153	.010
89	Rump: Left hind quarter	2 20	7.04	1.10	5.94	.69	.938	.512	.426	.037	.0825	.145	.102	.043
115	Rump: Right hind quarter	179 20	8.39	.95	7.44	.76	1.14	.506	.634	.054	.2570	.154	.141	.013
90	Loin: Left hind quarter	2 20	6.90	1.04	5.87	.69	.998	.577	.421	.035	.0798	.144	.095	.049
116	Loin: Right hind quarter	179 20	7.68	.98	6.70	.70	1.05	.445	.605	.066	.2213	.144	.137	.007

TABLE 57.—*Composition of 0.9 per cent sodium chlorid extract of meat expressed in terms of percentages of moisture-free and fat-free material.*

Serial No.	Description of sample.	Storage period.	Total solids.	Ash.	Organic extractives.	Acid as lactic.	Nitrogen.					Phosphorus.		
							Total soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Total soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
88	Round: Left hind quarter	2 20	30.00	4.13	25.87	3.18	4.16	2.29	1.87	0.168	0.3715	0.693	0.485	0.208
114	Round: Right hind quarter	179 20	33.64	4.30	29.34	3.27	4.62	1.94	2.68	.278	.9220	.665	.626	.039
	Change	177	+3.64	+.17	+3.47	+.09	+.46	−.35	+.81	+.110	+.5505	−.028	+.141	−.169
89	Rump: Left hind quarter	2 20	31.90	4.99	26.91	3.12	4.25	2.32	1.93	.168	.3738	.656	.461	.195
115	Rump: Right hind quarter	179 20	35.14	3.98	31.16	3.18	4.77	2.12	2.65	.226	1.0764	.644	.591	.053
	Change	177	+3.24	−1.01	+4.25	+.06	+.52	−.20	+.72	+.058	+.7026	−.012	+.130	−.142
90	Loin: Left hind quarter	2 20	31.45	4.72	26.73	3.14	4.55	2.63	1.92	.159	.3637	.658	.434	.224
116	Loin: Right hind quarter	179 20	31.99	4.08	27.91	2.92	4.37	1.85	2.52	.275	.9221	.599	.570	.029
	Change	177	+.54	−.64	+1.18	−.22	−.18	−.78	+.60	+.116	+.5584	−.059	+.136	−.195

10.52 per cent. A comparatively small increase, amounting to 1.01 per cent, took place in the acidity of the intermuscular fat. This increase is smaller than some of the increases which took place in the acidity of this fat in carcasses that had been stored for shorter periods of time.

The kidney and external fats from the stored quarter had strong, rancid odors, gave positive reactions for rancidity, and were of very poor quality in general. The intermuscular fat was of fair quality and gave no reaction for rancidity.

TABLE 58.—*Composition of fat.*

Serial No.	Description of sample.	Storage period.	Iodin number.	Refractive index 40° C.	Per cent acidity as oleic acid.	Rancidity.	Physical characters.
		D. H.					
91	Kidney fat: Left hind quarter....	2 20	41.72	1.4563	0.39	Neg.....	Normal.
117	Kidney fat: Right hind quarter...	179 20	39.56	1.4550	10.43	Sl. pos..	Very strong, rancid odor.
92	Intermuscular fat: Left hind quarter.	2 20	48.59	1.4573	.34	Neg.....	Normal.
118	Intermuscular fat: Right hind quarter.	179 20	49.26	1.4560	1.35	...do.....	Do.
93	External fat: Left hind quarter...	2 20	56.41	1.4583	.39	...do.....	Do.
119	External fat: Right hind quarter.	179 20	56.68	1.4570	9.87	Sl. pos..	Strong, rancid odor.

Table 59 shows the distribution of nitrogen and phosphorus upon the basis of 100 parts of the respective constituents in the fresh quarter.

Fairly marked decreases have taken place in the total nitrogen content of the round and loin, and a slight decrease in that of the rump. These losses in nitrogen confirm similar losses in this constituent that have taken place in all of the other experiments of this series except Experiment No. 1, where slight apparent gains in nitrogen were noted.

Marked increases took place in the soluble nitrogen content of the round and rump during storage, these increases being greater than those which took place in the same parts of the carcass in any of the previous experiments. On the other hand, there was a slight decrease in the soluble nitrogen content of the loin during storage.

Coagulable nitrogen shows fairly marked decreases in the case of the round and loin and an appreciable decrease in the case of the rump. These losses are not nearly so great as those which took place in Experiments Nos. 4 and 5, where the storage periods amounted to 63 and 74 days, respectively.

The amounts of noncoagulable nitrogen present in the different parts of the carcass have increased to a greater extent in this experiment than in any of the previous experiments. However, the increases in noncoagulable nitrogen in this experiment, where the

TABLE 59.—*Distribution of nitrogen and phosphorus on basis of 100 parts of the respective constituents at beginning of storage period.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
88	Round: Left hind quarter	2 20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
114	Round: Right hind quarter	179 20	94.77	111.16	84.88	143.34	165.64	248.18	196.34	93.64	85.07	96.06	129.06	19.10
89	Rump: Left hind quarter	2 20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
115	Rump: Right hind quarter	179 20	99.10	112.34	91.34	137.57	134.61	287.96	208.52	90.41	67.29	98.26	128.35	27.18
90	Loin: Left hind quarter	2 20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
116	Loin: Right hind quarter	179 20	94.93	96.13	70.49	131.27	172.92	253.53	216.07	92.08	95.77	91.08	131.35	12.96

TABLE 60.—*Distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus.*

Serial No.	Description of sample.	Storage period.	Nitrogen.							Phosphorus.				
			Total.	Soluble.	Coagulable.	Non-coagulable.	Proteose.	Amino.	Ammoniacal.	Total.	Insoluble.	Soluble.	Soluble inorganic.	Soluble organic.
		D. H.												
88	Round: Left hind quarter	2 20	100.00	27.60	15.20	12.40	1.12	2.47	0.27	100.00	22.02	77.98	54.58	23.40
114	Round: Right hind quarter	179 20	100.00	32.38	13.61	18.77	1.95	6.46	.56	100.00	20.02	79.98	75.21	4.77
	Change	177	0.00	+17.29	−10.43	+51.24	+74.78	+161.87	+107.34	0.00	− 9.08	+ 2.57	+37.80	−79.62
89	Rump: Left hind quarter	2 20	100.00	28.81	15.73	13.08	1.14	2.53	.28	100.00	25.35	74.65	52.46	22.19
115	Rump: Right hind quarter	179 20	100.00	32.66	14.50	18.16	1.55	7.36	.59	100.00	18.87	81.13	74.46	6.67
	Change	177	0.00	+13.36	− 7.82	+38.83	+35.84	+190.58	+110.77	0.00	−25.56	+ 8.68	+41.94	−69.94
90	Loin: Left hind quarter	2 20	100.00	30.95	17.89	13.06	1.08	2.47	.25	100.00	21.25	78.75	51.97	26.78
116	Loin: Right hind quarter	179 20	100.00	31.34	13.28	18.06	1.97	6.61	.56	100.00	22.11	77.89	74.12	3.77
	Change	177	0.00	+ 1.26	−25.75	+38.27	+82.15	+167.06	+127.76	0.00	+ 4.05	− 1.09	+42.62	−85.92

carcass had been held in storage for a period of 177 days, are only slightly larger than those that took place in Experiment No. 5, where the carcass had been held in storage for a period of only 74 days.

The increases that have taken place in proteose nitrogen are comparatively small, being only slightly greater than those which took place in the carcass stored two weeks, and not so large as those which took place in the carcass stored four weeks.

Amino nitrogen more than doubled during the 177-day storage period in each part of the carcass examined. That the largest increases were effected during the longest period of storage is in final conformity with the results obtained in the autolysis experiment.

Ammoniacal nitrogen increased to a greater degree during the storage period in this experiment than it had previously increased during the shorter storage periods, the increases each amounting to approximately 100 per cent.

The total phosphorus content of each portion of the stored quarter was less than that of corresponding portions of the fresh quarter. The average apparent decrease was greater than the average apparent decrease in this constituent in any of the previous experiments, and was accompanied by the largest average loss of total nitrogen. The cause of these apparent losses is not evident.

Table 60 shows the distribution of nitrogen and phosphorus expressed as percentages of total nitrogen and total phosphorus. These data are of particular interest in view of the fact that one of the quarters of this carcass of beef had been held in cold storage at a temperature above freezing for a period of nearly six months.

As regards the nitrogen compounds, the quarter of beef that had been held in cold storage for a period of 180 days contained a larger proportion of its total nitrogen in the forms of total soluble, noncoagulable, amino, and ammoniacal nitrogen, respectively, than did any of the carcasses that had been stored for shorter periods of time. On the other hand, the proportions of total nitrogen present in the forms of proteose and coagulable nitrogen had, in this quarter, values that were intermediate between their highest and their lowest values in this series of experiments.

Insoluble phosphorus, even with the long storage period of this experiment, showed irregular changes, increasing in the loin and decreasing in the round and rump, so that no additional light is thrown upon the nature of the changes in this constituent during cold storage.

Changes in total soluble phosphorus are irregular and have no determined significance.

The actual increases which occurred in the ratios of soluble inorganic phosphorus to total phosphorus during the storage period of this experiment are greater than the corresponding increases which have taken place during the shorter periods of previous experiments, although the change per cent in this ratio, in case of the round, is less than that obtained in Experiment No. 5. The changes, on the whole, are rather small in comparison with the length of the storage period; though it should be noted, in this connection, that the amount of preformed soluble inorganic phosphorus in the fresh meat was rather large.

The changes that took place in the ratios of soluble organic phosphorus to total phosphorus have rather less significance than the corresponding changes in the inorganic phosphorus ratios.

SUMMARY OF CHEMICAL AND PHYSICAL STUDIES.

The general purpose of the cold-storage experiments, the results of which have been reported in some detail, was to determine the cause, nature, and extent of the changes that take place in fresh beef during cold storage, with particular reference to the effect of such changes upon the wholesomeness and nutritive value of the product.

As regards the conditions of storage, the experiments may be divided into two groups, the first of which would include those experiments carried out in the bureau's cold-storage room, and the second of which would consist of the single experiment conducted in the packing-house cooler. The first group includes Experiments Nos. 1, 2, 3, 4, 5, and 7, while the second group consists of Experiment No. 6. The two series of experiments are of value in showing the effect of different conditions of storage upon the nature and extent of the changes which take place in beef during storage and upon the length of the storage period.

In the experiments of the first group the conditions of storage were fairly uniform, the temperatures varying between 32° and 36° F., and the humidity between 70 and 80 per cent of saturation. The principal variable element in these experiments was the length of the storage period, so that, in large part at least, the difference in the extent of the changes which took place in the beef in the several experiments may be considered as due to this factor.

In the case of Experiment No. 6, which was carried out in the packing-house cooler, the conditions of storage were also fairly uniform throughout the experiment. The temperature varied between 28° and 32° F., but remained, for the most part, at 32° F., and the humidity ranged from 92 to 95 per cent of saturation.

Certain differences were observed in the initial composition of the beef used in the several experiments, and these had to be taken into consideration in order properly to interpret the changes that took place in the meat during storage.

PHYSICAL CHARACTERISTICS OF THE BEEF.

In the series of experiments carried on in the bureau's cold-storage room, the principal effects of storage upon the physical characteristics of the beef were shrinkage in weight and a hardening and darkening of the exposed muscular and fatty tissues. The shrinkage in weight varied from 2.15 per cent in the case of the beef held in cold storage for 14 days to 10 per cent in that held in storage for 177 days. Slight growths of mold appeared on the exposed muscular tissues in the middle stages of this series of experiments, but did not become extensive even in the case of the beef stored for 177 days. In fact the progressive drying out of the meat during storage inhibited the growth of mold. The hardening and darkening of the tissues of the meat, together with its shrunken appearance after the longer periods of storage, undoubtedly lowered the market value of the product, entirely apart from any question as to its wholesomeness or nutritive value. On the other hand, the physical changes which took place in the beef stored for 2 and 4 weeks, periods which correspond to the length of time that beef is held in cold storage in commercial practice, were not marked and did not lower the market value of the product.

In the experiment which was carried on in the packing-house cooler, where the temperature was slightly lower and the humidity much higher than in the bureau's cold-storage room, the shrinkage in the weight of the beef at the end of the 54-day storage period amounted to 3.27 per cent, as compared with 5.26 per cent in the case of the beef stored in the bureau's cooler for only 28 days.

The beef stored in the packing-house cooler was covered with a heavy growth of mold after 54 days in storage, so heavy, in fact, that it appeared that the meat could not be carried safely in storage for a longer time, and the experiment was concluded. The beef was considered still to be in marketable condition. The lowered shrinkage and the increased growth of mold noted in this experiment were undoubtedly the result of the greater humidity of the packing-house cooler, as compared with that of the bureau's cold-storage room.

ORGANOLEPTIC PROPERTIES OF THE BEEF.

The principal effect of cold storage upon the organoleptic properties of the beef was a marked increase in tenderness; but the extent of this change did not bear a direct relation to the length of the storage period. In fact, the increase in tenderness of beef stored for from 2 to 4 weeks was practically as great as that in beef stored for much longer periods of time.

Although flavor is one of the qualities of meat in the judgment of which individuals may differ greatly, yet it was the opinion of the authors that, on the whole, storage did not improve the flavor of the meat. Storage caused a gradual change of flavor to the extent that the beef stored for the longer periods of time was designated as "old," and was considered in some cases to be less appetizing than the flavor of fresh meat. Similar changes were noted in the odor of the freshly cut surfaces of the cold-storage meats.

The quarter of beef that had been held in storage in the packing-house cooler for a period of 54 days possessed organoleptic properties that were similar to the beef that had been stored in the bureau's cold-storage room for approximately the same periods of time. The growth of mold upon this quarter of beef was a surface condition, and while it was indicative of conditions favorable to the rapid development of bacteria and the consequent deterioration of the meat, no such change had yet taken place.

Although in a few instances exposed portions of the stored quarters of beef showed signs of deterioration, yet in all cases, as judged by the organoleptic tests ordinarily applied, the edible portions of these quarters would have been classed as wholesome. The authors ate liberally of the test steak cut from each quarter of beef, both fresh and stored, and in no case did they suffer any ill effects from so doing. In this connection, however, it should be noted that the authors were healthy and well-nourished individuals.

CHEMICAL CHANGES IN THE BEEF.

Briefly summarized, the changes which took place in the chemical composition of the beef during storage consisted of a transformation of the more complex constituents of the meat into simpler compounds, with the consequent accumulation of certain of the end products of those changes. In general the extent of the changes increased with the period of storage. The changes were very similar in nature to, but less in extent than, those that took place in lean beef during aseptic autolysis, as reported in a previous section of this paper.

Since the results of the bacteriological studies of the beef have shown that there was no appreciable penetration of bacteria into the meat during storage it may be concluded that the changes which took place in the beef were due, in large part at least, to the action of enzyms. Exception must be made to the kidney and external fatty tissues, which were exposed to the action of bacteria.

The changes which took place in the individual constituents of the meat during storage and the significance of those changes as affecting the wholesomeness and nutritive value of the meat are discussed in the following paragraphs.

Moisture, fat-free basis.—Expecting in the case of the quarter of beef stored for 14 days the moisture content of the meat decreased during storage. In general the loss of moisture became greater as the period of storage was lengthened, but the loss occurred less rapidly in the meat stored in the packing-house cooler, with its high humidity, than in the beef stored in the bureau's cold-storage room at a lower humidity. These facts are in keeping with the observations made concerning the shrinkage in weight of the cold-storage beef.

Ash.—The slight irregular changes noted in this constituent are without significance.

Total nitrogen.—With the exception of the quarter of beef that had been held in storage for 14 days, where there was an apparent increase in the nitrogen content of the meat, each quarter of beef showed a slight apparent decrease in nitrogen content during storage. The increase in nitrogen in the one instance must be regarded as due to some unknown analytical error; but the fact that the nitrogen content of all the other quarters of beef that had been stored for longer periods of time decreased makes it appear that there was a slight actual loss of nitrogen from the meat during storage. However, the decreases were not distinct enough to make the results convincing.

Total soluble solids.—The changes that took place in this constituent during the storage of the beef did not bear a direct relation either to the length of the storage period or to the conditions of storage. The quarters stored for 14, 28, and 63 days showed considerable decreases in total soluble solids; that stored for 42 days showed practically no change; while those stored for 54, 74, and 177 days showed distinct increases. The decreases in the amount of total soluble solids that occurred during the storage periods are contrary to the commonly accepted idea that there is necessarily an increase in this constituent of meat during storage. It appears that there was first a decrease in total soluble solids in the early part of the storage period, and later an increase in this constituent as the storage period was lengthened. The probable explanation of these peculiar changes will be discussed in connection with total soluble nitrogen.

Ash of extract.—On account of an unavoidable analytical error encountered in the determination of this constituent, due to the necessity of correcting for a relatively large quantity of sodium chlorid in the presence of a small amount of ash, the data for this constituent are not considered to have any special significance.

Organic extractives.—The changes in this constituent were of the same general character as those which took place in the total solids.

Total soluble nitrogen.—The changes that took place in this constituent did not proceed in regular order. Beef stored for 14, 28, and 63 days showed slight decreases in total soluble nitrogen, while that stored for 42, 54, 74, and 177 days exhibited slight to appreciable gains in that constituent. On the whole the changes in total soluble nitrogen during storage were not large.

The interpretation of these changes, however, is of considerable significance. The probable explanation of the initial decrease in total soluble nitrogen and of the subsequent increase in that constituent is, in general, the same as that which has already been suggested to account for the similar changes observed in the autolysis experiment reported in a previous part of this paper. That explanation need not be repeated here.

The increases observed in the total soluble nitrogen content of meat stored for longer periods must be regarded as being due, in large part at least, to enzym action. In the light of present information the enzym protease may be considered as the active agent.

Coagulable nitrogen.—The changes that took place in this constituent during storage consisted of fairly marked decreases, which in general became larger as the storage period was lengthened. However, because of the irregular changes that took place in total soluble nitrogen, which in turn affected the amounts of coagulable nitrogen present in the meat at a given time, the full extent of the transformation of coagulable nitrogen into noncoagulable forms is not shown by the decreases in coagulable nitrogen, but is shown rather by the increases in noncoagulable nitrogen.

Noncoagulable nitrogen.—This constituent increased continuously throughout the cold-storage periods employed in these experiments. The average increase in the noncoagulable nitrogen in the beef stored for 14 days was 1.36 per cent, while the increase in the beef stored for 177 days was 37.39 per cent of the noncoagulable nitrogen originally present. In large part at least, the changes of coagulable protein into noncoagulable forms may be regarded as being due to the action of the enzym protease.

Proteose nitrogen.—While the relative increase in this constituent during storage was large in each experiment, there was no direct relation between the length of the storage period and the increase in proteose nitrogen. The average increase in this constituent during 14 days of storage amounted to 34.04 per cent and the increase during 54 days of storage amounted to 268.91 per cent of the amount initially present, while the increase observed in case of the quarter stored for 177 days amounted to but 57.72 per cent of the proteose nitrogen initially present. The proteoses are, of course, an intermediate product in the autolysis of muscle proteins, and no marked accumulation of this product during cold storage was to have been expected. While in some cases the increases in the proteose content of the cold-storage meat were relatively large, yet in no case did the proteose nitrogen constitute any considerable proportion of the total nitrogen of the meat, the maximum average percentage being 1.97 in the case of carcass No. 6, which had been stored for a period of 54 days.

Amino nitrogen.—Without exception, each quarter of beef contained more amino nitrogen at the end of its storage period than did the corresponding fresh quarter, and likewise, without exception, the longer a quarter was held in storage at a given temperature the greater was the relative increase in this constituent. In the quarter that was stored in the packing-house cooler for 54 days, however, the amino nitrogen did not increase by as great an amount as did that in the quarter held in storage in the bureau's cold-storage room for 42 days. This was probably due to the lower storage temperature in the first instance.

The conduct of this constituent in these experiments was entirely in harmony with the fact that the amino nitrogen, for the most part, represents the accumulation of amino acids, the end products of the autolysis of muscle proteins, and that, within certain limits, the extent of the autolysis increases as its duration and the temperature at which it occurs are increased. Although the enzym erepsin is probably most directly concerned in the splitting off of amino acids, yet undoubtedly all classes of proteolytic enzyms present in muscular tissue participate either directly or indirectly in bringing about the increase in amino nitrogen, so that the increase in this constitutent is theoretically the best index of the extent of proteolysis in muscular tissue.

In each of the cold-stored quarters of beef the relative increase in amino nitrogen was large, varying from an average of 16.57 to 163.22 per cent of the amount present in the fresh material. Likewise, the actual amounts present, though not really large, formed a considerable proportion of the total nitrogen, varying from less than 3 per cent to more than 7 per cent of the total nitrogen, according to the duration and temperature of storage. As the error involved in the determination of these amounts of amino nitrogen in meats is relatively small, the increase in this constituent undoubtedly affords not only the best theoretical, but also the best practical, measure of the extent of autolysis in cold-stored meats.

Ammoniacal nitrogen.—In general the behavior of ammoniacal nitrogen in this series of experiments was much the same as that of amino nitrogen, although the increases that occurred in ammoniacal nitrogen did not correspond as closely to the time and temperature of storage as did those in amino nitrogen, but involved an additional factor. It may be recalled that in the autolysis experiment the formation of ammoniacal nitrogen during the incubation of the beef took place less rapidly as this product accumulated in the material, even though the retarding agency, in all probability, was not the ammonia itself. Similar relations are to be observed in some cases in the cold-storage experiments.

The way in which ammoniacal nitrogen increases with the time of storage when the temperature of storage remains constant may be seen by comparing the results of Experiments Nos. 1 and 2 on the one hand, and Experiments Nos. 3, 4, and 7 on the other hand. The retarding effect of a lower temperature may be seen by comparing the results of Experiment No. 6, with its 54-day storage period, with those obtained during shorter periods of storage at higher temperatures. The slower rate of ammonia production that is observed when the amount of preformed ammonia is relatively large, can be seen by comparing the ammonia increases of Experiment No. 3 with those of Experiment No. 2, and the increases in the loins of Experiments Nos. 4 and 5.

On account of the many factors that seem to influence the formation of ammoniacal nitrogen and because of the small quantities of ammoniacal nitrogen found in the beef, even after long periods of storage, the changes in this constituent have not constituted a good index of the extent of autolysis in the cold-stored beef; nor can they be regarded as being of any practical significance. The production of ammonia is probably largely due to the combined action of several proteolytic enzyms.

Acidity.—The beef stored for 14, 28, and 177 days showed slight apparent decreases in acidity, while that stored for 42, 63, and 74 days exhibited from slight to appreciable gains in that constituent. The presence of acid-forming enzyms in muscular tissue is well known, and the increases that took place in the acidity of the meats were undoubtedly due, in large part at least, to enzym action.

Total phosphorus.—With the exception of the quarter of beef stored for 14 days, each cold-stored quarter contained less total phosphorus than the corresponding fresh quarter. This seeming loss of phosphorus was accompanied in every case but one by a corresponding loss in total nitrogen. Similar variations in total phosphorus and total nitrogen were observed during the autolysis experiment. Of themselves these data would go to show that phosphorus actually was lost from the meat during storage; yet, in view of the improbability of such an occurrence and the smallness of the apparent losses, the evidence would scarcely justify such a conclusion.

Insoluble phosphorus was determined by difference, and what is stated in the following paragraph applies inversely to this constituent.

Total soluble phosphorus.—The changes that occurred in total soluble phosphorus during the cold storage of the beef were of a very irregular nature. The changes were sometimes large and sometimes small, sometimes positive and sometimes negative, but in no case did they seem to bear any relation to any known factor. Even in Experiment No. 7, where the storage period was 177 days, two decreases and one increase in this constituent were observed. It can only be inferred that the solubility of some portion of the organic phosphorus was influenced by some obscure factor that was not properly controlled in these experiments, and which escaped detection in the autolysis experiment in consequence of the extensive cleavage of insoluble phosphorus. Obviously, therefore, in the present case no particular significance can be attached to these irregular changes.

Soluble organic phosphorus.—The changes that have occurred in the soluble organic phosphorus of the beef during the storage periods of these experiments appear to have been influenced not only by the length of the storage period and by the temperature of storage, but also by the relative amounts of preformed soluble organic and inorganic phosphorus contained in the fresh material. In order that these relations may be studied, therefore, the experiments must be classified, not only with reference to the time and the temperature of storage, but also with regard to the initial distribution of soluble organic and inorganic phosphorus. In reference to the latter factor, Experiments Nos. 2 and 4 should be placed in one group and the other experiments in a second group, since the material used in Experiments Nos. 2 and 4 each contained a greater proportion of total phosphorus in the soluble inorganic form and a smaller proportion in the soluble organic form than did the material used in any of the other experiments.[1]

If each of these groups be considered separately, and Experiment No. 6 be omitted from the second group because of its lower storage temperature, it will be seen that, in general, the cleavage of soluble organic phosphorus increases as the period of storage is lengthened. If Experiment No. 6, with its 54-day storage period, is compared with Experiment No. 3, with its 42-day storage period, it will be seen that the cleavage seems to be retarded by a reduction of the storage temperature. If Experiments Nos. 2 and 4 are compared with Experiments Nos. 1, 3, 5, and 7 it will be seen that, proportionately to the time of storage, the cleavage is less where the fresh material is comparatively rich in inorganic phosphorus and poor in soluble organic phosphorus than where the reverse is the case. This latter observation is in harmony with the results obtained in the autolysis experiment, where it was found that the rate of cleavage of soluble organic phosphorus grew less as the amount of soluble organic phosphorus diminished. (In the discussion of this constituent and the following, the data referred to are those contained in the last table of each experiment, and the changes referred to are those obtained by subtracting the figures for the stored quarter from those for the fresh quarter or vice versa. The reason for making the comparison in this way has been previously indicated.)

Inorganic phosphorus.—The changes in inorganic phosphorus that occurred during the storage of the beef appear to have been influenced by the same factors that influenced the changes in soluble organic phosphorus, viz, the length of the storage period, the temperature of storage, and the distribution of organic and inorganic phosphorus in the fresh material. The factors that retarded the cleavage of soluble organic phosphorus, of course, also retarded the formation of inorganic phosphorus; and the factors that accelerated the one accelerated the other. The principal difference between the changes that occurred in soluble inorganic and in soluble organic phosphorus is that the amount of the first increased, while that of the second decreased. Likewise, the changes in soluble inorganic phosphorus afford a somewhat better idea of the phosphorous cleavage that takes place during cold storage than do the corresponding changes in soluble organic phosphorus, since the inorganic phosphorus is an end product and is not affected by the irregular changes in the solubility of the organic phosphorous compounds.

It is not clear from these experiments whether the inorganic phosphorus that was formed during storage was derived from phosphatides, nucleoproteins, phosphocarnic acid, or other organic phosphorous compounds. Undoubtedly, however, it resulted chiefly through enzymatic activity, although the particular enzyms that were concerned in its production are not indicated with certainty. Presumably, however, the phosphonucleases were less concerned than were the phosphatases.

Refractive indices.—The fats from the beef stored for the shorter periods showed practically no changes in their refractive indices, while the fats from the beef which had been stored for 74 and 177 days showed appreciable decreases in those values that are to be

[1] Experiment No. 7 in reality forms a third group, less than midway between the other two. This distinction, however, has not been made in order to avoid complicating the subsequent discussion.

explained by the comparatively large increases in the amount of free fatty acids present in those samples.

Free fatty acids.—There was a marked and continuous increase in the free fatty acid content of the external and kidney fats during the course of the storage experiments and a corresponding deterioration in the quality of those fats. The average actual increase in the acidity of the two fats ranged from 0.46 per cent in the case of the beef stored 14 days to 9.76 per cent in the case of that stored 177 days. The changes in the acidity of the intermuscular fat were comparatively small, varying from an increase of 0.17 per cent in the case of the beef stored for 14 days to an increase of 1.42 per cent in the case of that stored for 74 days. The reason for the slight increase in the acidity of the intermuscular fat as compared with the large increases in the acidity of the kidney and external fats is clearly apparent. The intermuscular fat was protected from bacteriological invasion by its covering of muscular and external fatty tissues, while the kidney and external fats were exposed to the invasion of molds and bacteria. The changes that took place in the intermuscular fat were due, in very large part at least, to the action of the enzym lipase, while the changes that took place in the kidney and external fats were due principally to bacterial action.

EFFECTS OF COLD STORAGE UPON THE NUTRITIVE VALUE OF THE BEEF.

Several factors must be taken into consideration in order properly to interpret the results of these experiments in terms of their effect upon the nutritive value of the meat. The more important factors are as follows: (1) Changes in the moisture content of the meat; (2) changes in the proportions of nonedible and edible meat in the quarters of beef; (3) changes in the composition of the meat.

The analytical data obtained in these experiments show that, with the exception of the quarter of beef that had been stored for 14 days, each of the quarters lost moisture during storage, and that in general the decrease in the moisture content of the meat was greater the longer the storage period. This loss of moisture is in effect a process of concentration, causing an actual increase in the amount of food constituents present in a given weight of stored meat, as compared with that present in a like weight of fresh meat. Thus, by referring to Tables 19, 26, 33, 40, 47, and 54 it may be noted that the average percentages of total nitrogen, fat, and ash increased during the storage period of each experiment, and that in general the increase was greater the longer the period of storage. These data show the composition of the lean meat and are a fair indication of the extent to which the nutritive value per given weight of meat was increased through loss of moisture.

The increase in nutritive value, however, is only apparent, not real; for while the loss of moisture effects an increase in the nutritive value of the meat per unit weight, it also diminishes the weight of the carcass; so that at best the carcass contains no more nutritive material after storage than before. Indeed, the available food material in the carcass tends to become less; for, in consequence of the drying out and deterioration in quality of the exposed muscular and fatty tissues, there is greater wastage in the preparation of the retail cuts from cold-stored meats than from fresh meats; and the wastage becomes greater as the storage period is lengthened, other conditions being the same.

The third factor to be considered is the effect of the changes in the nature of the constituents of the meat upon the nutritive value of the product. These changes have to do only with the edible portions of the beef.

The changes in the nitrogenous constituents of the meat have been in the nature of a process of autodigestion, the more complex nitrogenous compounds having been broken down into simpler compounds. These changes are represented in Tables 12 to 60, inclusive, chiefly by decreases in coagulable nitrogen and by increases in amino nitrogen. In general the extent of these changes has been greater the longer the period of storage. Table 60 shows that in the fresh quarter of beef from 2.47 to 2.53 per cent of the total nitrogen was present as amino nitrogen, while the corresponding quarter after having been stored for 177 days contained from 6.46 to 7.36 per cent of its total nitrogen in that form, the increases having amounted to 3.99 and 4.83 per cent, respectively.

In the light of our present knowledge concerning the functions of amino acids in human nutrition, it seems improbable that the changes that have taken place in the nitrogenous constituents of the meat, even after very long periods of storage, have been such as to affect appreciably the nutritive value of the product.

The changes that have taken place in the other constituents of the cold-storage beef have consisted principally in the breaking down of soluble organic phosphorous compounds with a corresponding formation of inorganic phosphates. Thus, the fresh quarter of carcass No. 7 contained from 22.19 to 26.78 per cent of its total phosphorus in the form of soluble organic phosphorus, while the quarter stored for 177 days contained but from 3.77 to 6.67 per cent of its total phosphorus in that form. It is, therefore, apparent that a very marked change has taken place in the nature of the phosphorous compounds.

The question as to the relative nutritive value of organic and inorganic phosphorous compounds is one concerning which there is considerable difference of opinion among those who have investigated the subject. While it has been determined that, under certain conditions, inorganic phosphates can be made to supply the phosphorus requirement of the body, yet it has by no means been established that phosphorus in inorganic combination has a nutritive value equal to that of the organic forms of phosphorus. In the light of our incomplete knowledge concerning the relative nutritive values of organic and inorganic forms of phosphorus, no positive conclusion can be drawn regarding the effects of the changes in the nature of the phosphorous compounds upon the nutritive value of the meat.

On the whole it would appear that the chemical changes that occurred during the storage of beef in these experiments did not appreciably affect the nutritive value of the meat when the period of storage was limited to that customarily employed in commercial practice. Indeed, even when the period of storage was greatly prolonged, evidence is lacking to show that the nutritive value of the meat was diminished. Yet, in view of the more extensive chemical changes that took place during the longer periods of storage and on account of the deficiency of our knowledge regarding the nutritive values of the various cleavage products, it is by no means impossible that the nutritive value of beef may be decreased by unduly long periods of storage.

FACTORS AFFECTING THE TIME THAT FRESH BEEF CAN BE STORED AT TEMPERATURES ABOVE FREEZING.

One of the objects in conducting the series of experiments reported in this paper was to determine the length of time that fresh beef could be held in cold storage at temperatures above freezing and remain in wholesome condition. The results of these experiments and of observations upon the commercial handling of fresh beef in cold storage have shown that the possible length of the storage period is affected by a number of factors. On account of the importance that has been attached to the time element in the cold storage of fresh beef, and in the storage of other fresh meats as well, it has seemed desirable to present a brief discussion of this phase of the subject.

The principal factors which affect the length of time that fresh beef can be held in cold storage at temperatures above freezing are as follows: (1) The character of the beef; (2) the temperature of storage; (3) the humidity of the cold-storage room.

Character of beef.—The condition of beef, as regards its degree of fatness or finish, is an important factor in determining the length of time that the beef will keep in cold storage. Thin, soft carcasses of old cows or grass-fed cattle are apt to undergo comparatively rapid deterioration in cold storage. The large exposed surface of muscular tissue and the soft character of the meat offer favorable conditions for the development of molds and bacteria. It is generally recognized by packing-house men that beef of this character must be handled with dispatch. On the other hand, highly finished carcasses from prime, grain-fed cattle will keep in cold storage for a much longer time. The flesh of such carcasses, which is firm in character, is usually covered in large part with a surface deposit of fatty tissue, which becomes firm on cooling and through loss of moisture, and thus aids in protecting the muscular tissue against bacterial invasion.

Temperature of storage.—In commercial practice chilled beef is ordinarily held in cold storage at a temperature between 34° and 36° F., although occasionally temperatures as low as 30° F. or as high as 40° F. may be employed. A temperature of 40° F. is regarded as about the upper limit of safety in the handling of fresh beef in cold storage, while it will freeze at a temperature slightly under 31° F. Other conditions being the same it is clearly apparent that chilled beef will keep longest at 31° F.

Humidity of cold-storage rooms.—The importance of dry coolers for the proper handling of chilled beef is generally recognized. As a rule, however, no special means are used to regulate the humidity of beef or other fresh-meat coolers, the desired condition usually being obtained by the proper construction and management of the coolers. Various factors may affect the humidity of coolers, but they will not be discussed.

There seems to be practically no information available regarding the humidity of packing-house coolers in this country. In order to secure accurate information on this subject, humidity readings were taken in 14 beef coolers in 6 modern meat-packing establishments. The results of these observations are presented in Table 61:

TABLE 61.—*Humidity of beef coolers in six meat-packing establishments.*

Cooler No.	System of refrigeration.[1]	Condition of cooler.	Per cent humidity.	Remarks.
1	Sheet brine	Good	87	Half filled with beef killed 3 days previously.
2	Closed brine coil	do	95	Half filled with chilled beef.
3	Sheet brine	do	92	Do.
4	do	do	95	Cooler for ripening cuts of meats for hotels, etc. Filled with cuts of beef, many of which showed growths of molds.
5	do	Air filled with water vapors coming from adjoining cooler being filled with warm beef.	100	Filled with chilled beef.
6	do	Good	92	Half filled with chilled beef.
7	Direct expansion of ammonia in overhead bunker.	Fair. Walls and ceiling damp.	93	Filled with chilled beef.
8	do	Fair	92	Do.
9	Closed brine coils	Fair. Some condensation of moisture on ceiling.	93	One-third filled with chilled beef.
10	do	Fair	93	One-half filled with beef, mutton, veal, and "edible offal."
11	Brine spray	Fair. Walls and ceiling damp.	93	One-third filled with chilled beef.
12	do	Good	93	Filled with chilled beef.
13	do	do	92	Nearly filled with chilled beef.
14	Closed brine coil	do	95	Filled with chilled beef.

[1] Overhead bunkers were used in each cooler.

The data presented in Table 61 show that for the most part the humidity of the beef coolers ranged from 92 to 95 per cent of saturation. Data showing the humidity of fore coolers filled with warm beef are not presented, since observations that have been made in such coolers have shown the air to be saturated with water vapors.

The effects of humidity upon the length of time that fresh beef can be held in cold storage are shown very clearly by the results of the cold-storage experiments carried on in the bureau's cold-storage room as compared with the one conducted in the packing-house cooler. The character of the beef was practically the same in the two cases, and the temperature of the packing-house cooler was slightly lower than that of the bureau's cold-storage room. The chief variable factor was humidity. The humidity of the bureau's cooler ranged from 70 to 85 per cent of saturation; that of the packing-house cooler from 92 to 95 per cent. The much higher humidity of the packing-house cooler was undoubtedly the reason why it was impossible to hold beef in storage in that cooler for longer than 55 days, whereas beef was held in the bureau's cold-storage room, having a slightly higher temperature but a much lower humidity, for as long as 177 days.

These observations emphasize the importance of humidity as a factor affecting the length of time that fresh beef can be held in cold storage.

In addition to the three important factors which have been discussed as affecting the storage period of fresh beef, various other factors may under certain conditions exert their influence.

Summary.—In light of the various factors that affect the length of time that fresh beef can be held safely in cold storage at temperatures above freezing, it is clearly impracticable to attempt to insure the wholesomeness of the product merely by limiting the duration of storage. The wholesomeness of cold-stored beef must be judged by other considerations besides the length of time that the product has been held in cold storage.

GENERAL SUMMARY.

The chemical changes that took place in the muscular tissue of beef held in cold storage at temperatures above freezing for periods ranging from 14 to 177 days consisted chiefly in increases in acidity; in proteose, noncoagulable, amino, and ammoniacal nitrogen; and in soluble inorganic phosphorus; while decreases occurred in coagulable nitrogen and in soluble organic phosphorus. On the whole these changes were of a progressive nature. The chemical changes that took place in the fatty tissues of the beef consisted chiefly in marked increases in the acidity of the kidney and external fats.

On the whole the chemical changes that took place in the muscular tissue of the beef during storage were similar in nature to but less in extent than those that were caused by enzymatic action when lean beef was autolyzed under aseptic conditions for periods ranging from 7 to 100 days.

The chemical changes that took place in the muscular tissue of the beef during storage were without appreciable effect either upon the nutritive value or the wholesomeness of the edible portions of the product; but the changes that took place in the kidney fat and external fatty tissue after the longer periods of storage rendered them unsuitable for human consumption.

The bacteria and molds which grew on the surface of the cold-stored meats did not penetrate the muscular tissue to any great depth. The increased tenderness noticed in the cold-stored meats could not be attributed to bacterial action; and no noticeable change in the histological structure of the muscle fibers was noticed after 11 weeks of storage.

The chemical changes which took place in the muscular tissues of the beef during storage may be regarded as largely due to enzym action.

The principal effect of storage upon the organoleptic properties of the beef was a marked increase in tenderness of the meat. This change did not appear to progress appreciably after the beef had been held in storage for from two to four weeks. While the flavor also changed, individuals would probably not agree as to whether the change was in the nature of an improvement or a deterioration.

Beef was held in cold storage at temperatures above freezing in an experimental cooler for as long as 177 days, whereas it was possible to hold beef in storage in a cooler in a modern packing house for only 55 days. The shorter storage period in the second instance was due to the much higher humidity of the packing-house cooler as compared with the experimental cooler.

The length of time that fresh beef can be held in cold storage at temperatures above freezing and remain in wholesome condition is dependent upon a number of factors, among which the temperature and humidity of the storage room and the character of the beef are of the most importance.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 434

Contribution from the States Relations Service, A. C. True, Director, and the Bureau of Animal Industry, A. D. Melvin, Chief

Washington, D. C. ▼ November 4, 1916

JUDGING THE DAIRY COW AS A SUBJECT OF INSTRUCTION IN SECONDARY SCHOOLS.[1]

By H. P. Barrows, *Assistant in Agricultural Education, States Relations Service,* and H. P. Davis, *Dairy Husbandman, Bureau of Animal Industry.*

CONTENTS.

	Page.		Page.
Introduction	1	Practice judging	16
Classroom discussion	1		

INTRODUCTION.

The scoring and judging of the dairy cow is rapidly becoming popular as a practicum in the teaching of agriculture in secondary schools. The work has done much to arouse interest in animal husbandry and dairying. A need has been felt for specific directions as an aid toward making this work more practical, and it is the aim of this bulletin to help fill this want.

CLASSROOM DISCUSSION.

Use of illustrative material.—When conditions approach the ideal the greater part of stock judging is learned with the animals to be judged present (fig. 1). As a matter of convenience preliminary lessons are usually given in the classroom. The teacher should bear in mind, however, that the student learns largely through what he sees, and should make use of an abundance of illustrative material. Before proceeding with a study of the dairy type the student should learn the names of the parts of a cow. It is not safe to assume that the high-school student knows all the terms used in judging. A diagram such as given in figure 2 is useful in showing the ideal dairy type as well as in giving the names of parts. This outline may be made into a chart or copied upon the blackboard. If drawn upon the board the names of the parts may be erased and the students

[1] Prepared under the direction of C. H. Lane, Chief Specialist in Agricultural Education.

NOTE.—This bulletin is intended for the use of teachers of secondary agriculture.

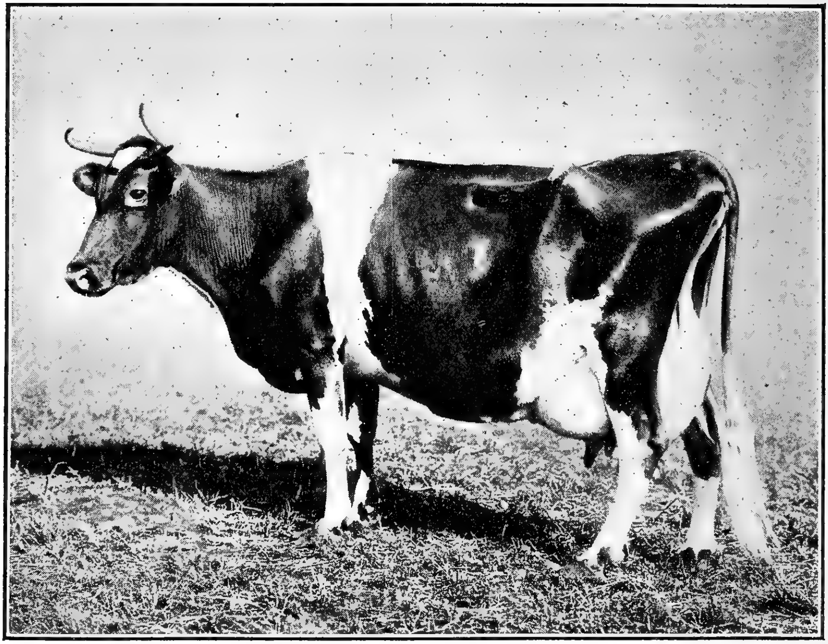

FIG. 1.—A good dairy type.

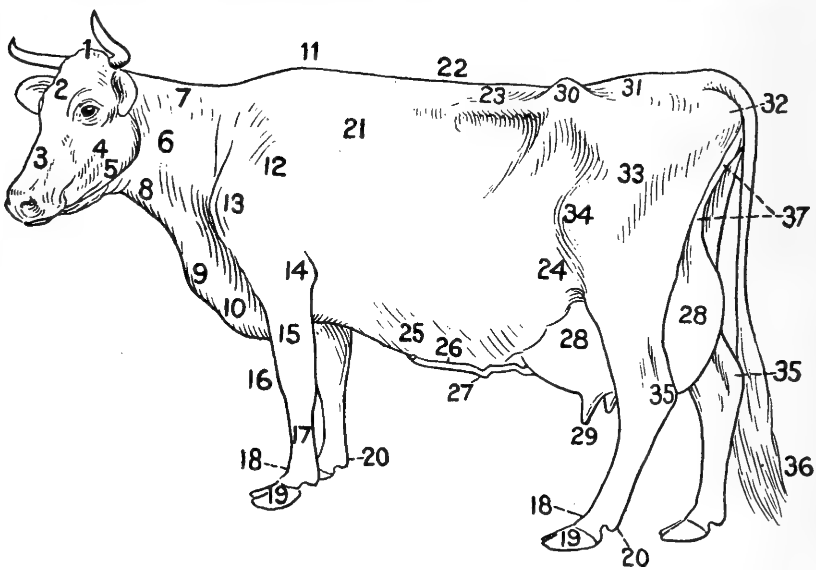

FIG. 2.—Outline of dairy cow with parts named: 1, poll; 2, forehead; 3, bridge of nose; 4, cheek; 5, jaw; 6, neck; 7, crest of neck; 8, throat; 9, dewlap; 10, brisket; 11, withers; 12, shoulder; 13, point of shoulder; 14, elbow; 15, arm or forearm; 16, knee; 17, shank; 18, ankle; 19, hoof; 20, fetlock; 21, crop; 22, chine—back; 23, loin; 24, flank; 25, milk well; 26, mammary vein or milk vein; 27, navel; 28, udder; 29, teats; 30, hook, or hook bone, hips; 31, pelvic arch; 32, pin bone, or rump bone; 33, thigh; 34, stifle; 35, hock; 36, switch or brush of tail; 37, escutcheon.

asked to fill them in. While discussing the dairy type it is well to have illustrations of good dairy cows constantly before the students. The teacher should make use of good pictures of prize winners as they appear in live-stock journals. If files of these papers are not kept, the good illustrations should be clipped and mounted upon cards for classroom use. A projection lantern with an opaque attachment will be found valuable in this work.[1]

The typical dairy cow.—In order to judge the dairy cow intelligently the student should understand that the modern dairy animal is very highly organized, virtually a living machine, the chief function of which is to make a valuable human food out of grains and coarse fodders. Originally cows gave only milk enough to support their calves until they were able to eat sufficient other food for self-support; but man, through selective breeding, with care and good feeding, has developed animals which yield a large surplus of milk. All so-called dairy cows do not yield a profitable surplus. As the expense of maintenance is large and variation in milk production is great, many cows are being kept which do not give milk enough to pay for their keep. One of the most important phases of dairy management is the elimination of unprofitable animals (fig. 3). It

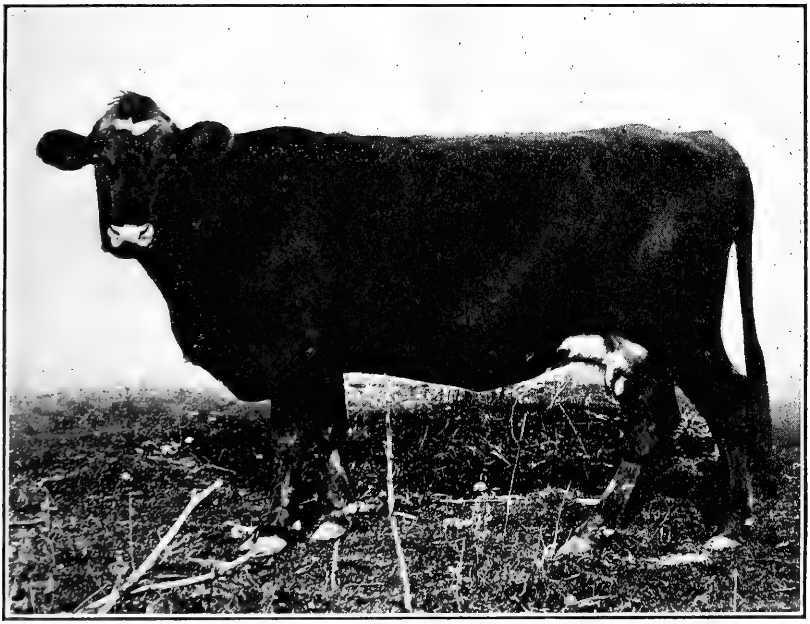

FIG. 3.—An unprofitable dairy cow.

[1] Lantern slides illustrating types and breeds of cattle, including the illustrations of this bulletin, may be obtained from the Office of Agricultural Instruction of the States Relations Service. Charts and stencils for use on blackboards may be made by tracing the outline of a diagram thrown on paper or cloth by a lantern.

is also important to know which of those yielding a profit are the best, that their offspring may be used in improving the herd. Lessons in judging are an important part of school work in dairying, as they aid the student in learning the desirable points of dairy animals.

How dairy cows are judged.—The teacher should bear in mind that the aim of the lesson is to give the student such knowledge concerning the dairy cow, and to develop his judgment to the extent, that he will get full value in buying or selling cows. If a practical dairyman of good judgment is buying a cow he wants to know the amount of feed she consumes, how much milk she is giving, the percentage of butter fat, and her record for maintaining the milk flow. An accurate milk record will mean much in indicating her value. He will want to milk the cow himself, to watch her eat and drink, and to be assured that she is in good health. If he is going to use her for breeding purposes, he will desire to learn what he can of her breeding and of her ability to transmit her qualities to her offspring. If she is a registered animal, he may learn a good deal from her pedigree. The importance of these points may be impressed by having students weigh and test the milk of cows in the district, keep records of the milk and fat produced, and study the records of production of ancestors in their pedigrees.

If the keeping of herd records is made one of the home projects of the students, it will be well for them to learn the methods used in testing cows in cow-testing associations and for advanced registry. Information may be obtained from the United States Department of Agriculture and from the breed associations.

Records of production are not always kept, and frequently it is desirable to know the value of cows not giving milk. Fortunately, there is a marked correlation between the form or type of dairy cows and their power to produce. It is very important that the dairyman know what constitutes true dairy conformation in milch cows, so school work in judging becomes largely a study of dairy types.

The dairy type.—If beef animals have been studied prior to taking up the work with dairy breeds, from the beginning there will be a natural comparison of the beef type with the dairy type (fig. 4). If an outline of a beef animal has been on the blackboard it will be helpful to transform it to represent a dairy cow before the students. Charts and pictures will be helpful in bringing out the contrast between the two types (fig. 5).

The functions of production and reproduction in dairy cows are so closely related that the form which indicates heavy production will usually denote a good breeder. When viewed from the side,

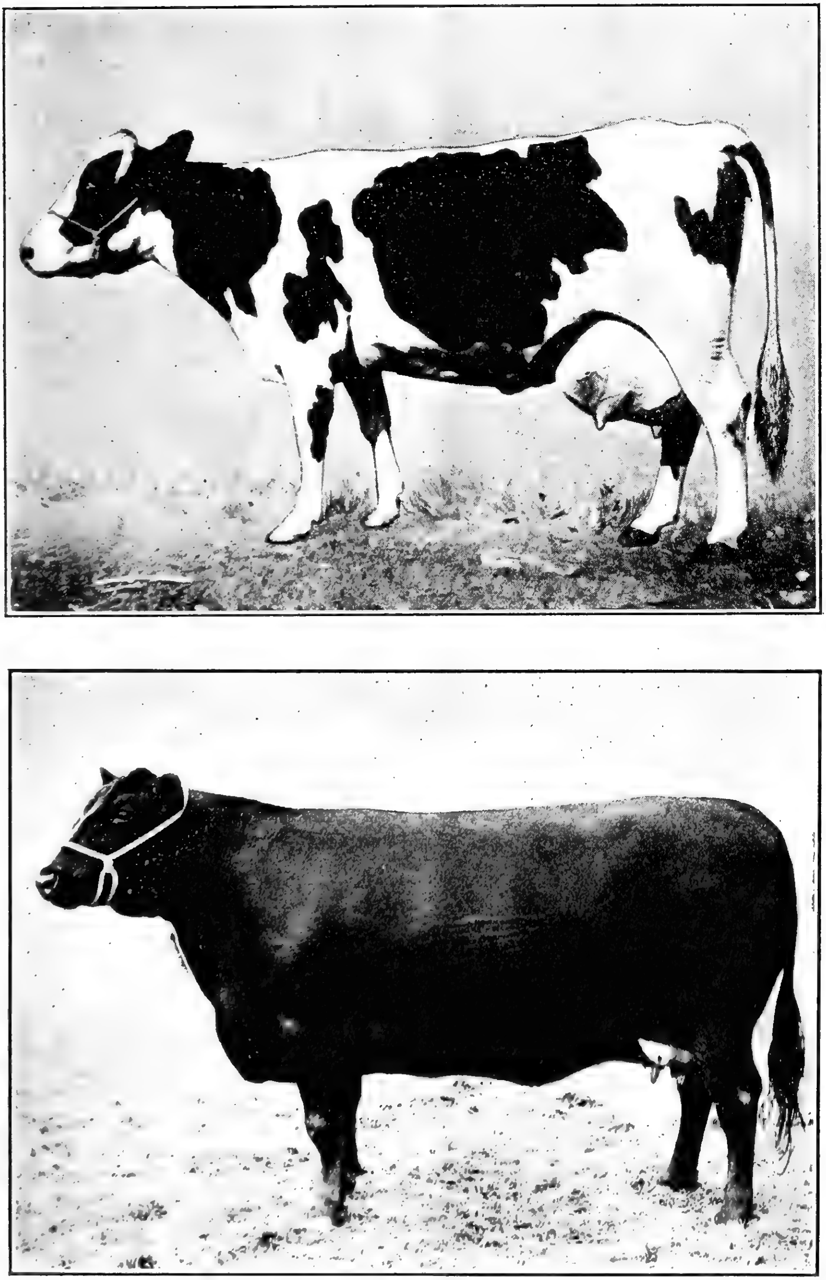

Fig. 4.—Comparison of (upper) dairy and (lower) beef form.

one great difference in conformation becomes at once apparent. While the beef cow has a short, square, and blocky appearance, with short, thick neck, straight back, deep body, and short legs, the dairy cow shows an angular, wedge-shaped body with slender neck, incurving thighs, and large udder development.

It should be borne in mind that the transformation of feed into milk is an intricate process which goes on within the animal and that the various points of conformation particularly noted in the dairy type are but indications that this process will be carried on efficiently. As an aid to students in examining an animal in a systematic manner and in order that no details may be overlooked by

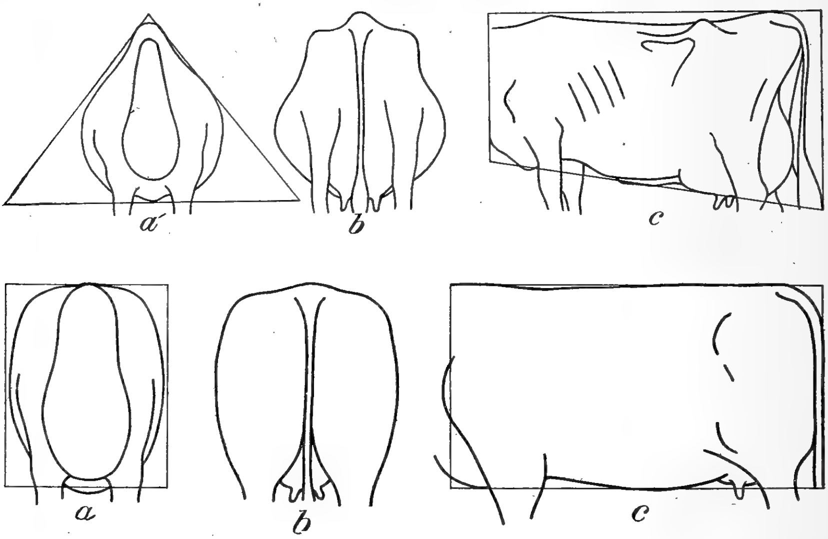

FIG. 5.—Outlines showing comparison of (upper) dairy and (lower) beef type from (a) front, (b) rear, and (c) side views.

beginners, score cards are used in stock judging. The score card is a classification of the points of the animal, giving to each a weight or percentage intended to indicate its relative importance to the whole. These points relate, of course, to the external form of certain portions of the animal's body and so far as is possible have a direct relation to the function of that organ or part. As is true with all classifications, there should be as little overlapping as possible in the divisions. The following-described cards for dairy animals are offered as embodying many of the best features of such score cards in use in the agricultural colleges. It must be understood that these are general score cards for dairy types.

General score card for the dairy cow.

Points.		Perfect score.	Percentage value.	Student's score.	Instructor's score.
1. General form		9			
Wedge shaped, when viewed from side, top, and front	6				
Size for the breed—Jersey, 800 pounds; Guernsey, 1,050 pounds; Ayrshire, 1,000 pounds; Holstein, 1,200 pounds	3				
2. Quality		7			
Hide—thin, mellow, pliable, and loose	2				
Hair—fine, soft	1				
Secretions—abundant, yellowish	1				
Flesh—muscular, free from bunchiness	1				
Veins—large and prominent	1				
Bone—fine and clean	1				
3. Head		6			
Forehead—broad between the eyes and dished according to breed	1.0				
Face—medium in length, clean cut in outline, dished below eyes	.5				
Nostrils—large	1.0				
Muzzle—broad, but not coarse	1.0				
Jaws—wide at base, strong	.5				
Ears—medium sized, thin, hair fine, blood vessels showing, secretion abundant	.5				
Eyes—full, prominent, clear, and bright	1.0				
Horns—small at base, incurving, attached close together at poll	.5				
4. Neck		2			
Moderately thin, of good length, nearly free from loose skin, neatly joined, throat clean.					
5. Forequarters		11			
Shoulders—withers sharp; shoulder blades lean	2				
Chest—broad and deep, well sprung foreribs; large heart girth; moderately full crops; brisket light	8				
Forelegs—straight, fine bone, strong	1				
6. Body—capacity		18			
Back—straight, strong, vertebræ prominent.	5				
Ribs—long, flat, well sprung, wide apart	3				
Abdomen (barrel)—long, deep, broad, well held up; loin broad, strong and level; flanks low	10				
. Hindquarters		12			
Hips—wide apart, prominent	3				
Rump—long, wide, level	3				
Pin bones—widely spaced, on level with hips.	3				
Thighs—incurving; escutcheon broad, extending well up on pin bones	1				
Tail—tapering, fine boned, long and neatly set on; switch, long	1				
Hind legs—squarely placed not sickle hocked, bone fine	1				
8. Mammary system		35			
Udder—large; quarters even and not cut up between; extending well up behind and well forward in front; not fleshy; soft and pliable	20				
Teats—squarely placed; even in size; of convenient size for milking; free from lumps, not leaky or hard to milk	8				
Mammary veins and wells—veins long, branching, tortuous, entering body well forward; wells large	7				
Total		100			

General score card for the dairy bull.

Points.		Perfect score.	Percentage value.	Student's score.	Instructor's score.
1. General form		16			
Masculinity	11				
Size for the breed—Jersey, 1,200 pounds; Guernsey and Ayrshire, 1,500 pounds; Holstein, 1,600 pounds	5				
2. Quality		10			
Hide—thin, mellow, pliable, loose	3				
Hair—fine, soft	2				
Secretions—abundant, yellowish	1				
Flesh—well muscled, free from bunchiness	1				
Veins—large, prominent	1				
Bone—strong and clean	2				
3. Head		10			
Forehead—very broad between the eyes, slightly dished	2				
Face—medium in length	1				
Nostrils—large	1				
Muzzle—broad	2				
Eyes—prominent, large, clear, bright	3				
Horns—well proportioned	1				
4. Neck		5			
Medium in length, very large prominent crest; neatly joined; throat free from loose skin.					
5. Forequarters		16			
Shoulders—withers moderately sharp; well muscled	5				
Chest—broad, deep, large heart girth, crops full, brisket moderate in size	10				
Fore legs—straight, squarely placed, wide apart, strong bone	1				
6. Body—capacity		19			
Back—straight, strong, vertebræ prominent	7				
Ribs—flat, well sprung, wide apart	2				
Abdomen (barrel)—long, deep, broad, well held up; loin broad, strong, level; flanks low	10				
7. Hindquarters		16			
Hips—wide and prominent	3				
Rump—long, wide, level	6				
Pin bones—widely spaced, on level with hips	4				
Thighs—incurving	1				
Tail—tapering; fine bone; neatly set on; long, fine switch	1				
Hind legs—squarely placed, not sickle hocked, bone clean and strong	1				
8. Rudimentaries		6			
Teats—squarely and evenly placed; large	3				
Mammary veins—large, tortuous	2				
Milk wells large	1				
9. Scrotum		2			
Well developed—strongly held up.					
Total		100			

CLASSIFICATION OF POINTS IN REFERENCE TO UTILITY.

Having a thorough knowledge of the names and locations of the parts of the cow, the next problem is their classification from a functional point of view. There are certain fundamental points covering the animal as a whole or a combination of a number of organs which will be first considered.

General form.—The general impression as to form which the judge receives when an animal is brought before him is an important consideration. This varies greatly between beef and dairy animals and is often termed "dairy type" or, in referring to animals of an individual breed, "breed type." "Wedge shaped" defines this general form. There are three distinct wedges to a typical dairy cow—namely, side, top, and front.

Side wedge: The side wedge is best observed by standing 30 feet or more from the cow and to her side. The lines of this wedge are the top and bottom lines of the cow. The point of the wedge is at the nose and the wide part at the flank. This wedge is most commonly defective on account of the top line not being straight. This may be caused by a sway back, a drooping rump, or a neck which is set at an angle to the back. A sway back or a sloping rump is much more serious than a neck which forms an angle with the backbone.

Lack of depth in the flank is a serious defect in the side wedge of a dairy cow and is usually accompanied with lack of capacity in the barrel and faulty mammary development. The angle of all wedges should be as wide as possible. The bottom line of the cow, forming one side of this wedge, can not be expected to be straight in the same sense that the top line is straight. There will be depressions and irregularities, but the general outline of the wedge should be present. The lower line will begin at the nose, touch at the brisket, follow the lower line of the stomach, and touch the lowest point in the udder.

Top wedge: The point of the top wedge is at the withers, with the lines drawn on either side between the point of the withers and the hip bones. The plane of the wedge is horizontal, while those of the side and front wedges are perpendicular. This wedge is defective when the withers are not sharp, the lines not straight, or the hip bones not wide enough apart. The lines are not straight when the ribs are not well sprung or when the loins are weak.

Front wedge: The point of the front wedge is at the withers. The lines follow the shoulder blades, the wide part being at the junction of the shoulder blades and the forelegs. The wedge shape seems to have a direct relation to dairy production in the dairy cow, but inasmuch as this relation in most cases is in connection with individual organs it will come up under a detailed discussion of the parts.

Size: Other things being equal, the larger an animal, the better. Generally size and quality are not closely correlated and the dairyman is led to choose a happy medium. It is true, however, that an undersized animal is undesirable even though it possesses extreme quality. The aim should be to obtain all the size possible with good quality.

Quality.—Quality is indicated by a thin, loose, pliable skin; medium-sized, clean, closely knit bones, and firm, clean, muscular tissue (fig. 6). The mucous membranes are the extension of the external skin; coarseness in the hide indicates the same condition in the mucous membrane. The membranes of the stomach and intestines are active agents in the digestion and assimilation of the feed. Experience and observation show that coarseness or stiffness in the skin is likely to be associated with poor digestive and assimilative powers. A spongy, coarse bone is objectionable because it is not strong, and is likely to be associated with low vitality and general inefficiency. Excessive flesh on a dairy cow while in milk indicates that there is not the desired specialization of milking function, but rather that the feed is used to produce flesh. The flesh should be muscular and free from fat.

Beginning at the head, the individual parts of the cow will now be taken up and an attempt made to describe the desirable form which indicates production.

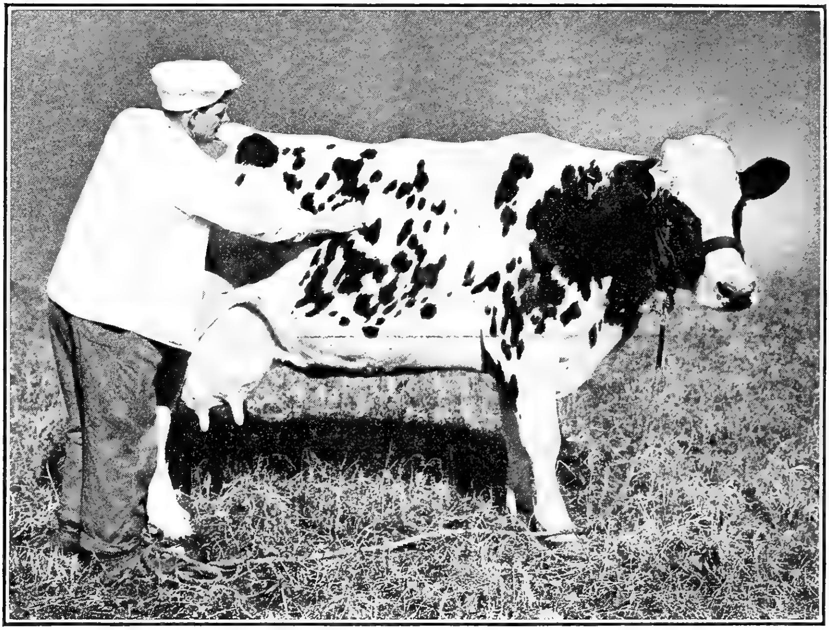

FIG. 6.—The nature and condition of the digestive organs is revealed in the skin and its covering of hair.

Head.—The heads of the male and female are much the same except that more size and heaviness are expected in that of the former. As a whole, the head should have a clean cut outline and be free from any coarseness of bone, flesh, or skin. In the bull score card more weight is given this part than in the cow score card. This is owing to the fact that the general character of the bull and his masculinity are evidenced in his head (fig. 7). The main function performed by the head is the taking in and mastication of feed. A strong, muscular muzzle and jaws indicate ability to handle large quantities of feed. The form and quality of face, forehead, eye, and horn indicate the nervous energy and refinement essential to productive ability.

Neck.—The necks of the cow and the bull are radically different. That of the cow should be of medium length, slender, free from flesh and loose skin; it should be small at the junction with the head and should join the shoulders smoothly. The neck of the bull should be of medium length, small at the head and swelling into a prominent crest. The crest in the bull indicates masculinity and should be both high and broad.

Forequarters.—Withers: The withers should be sharp, the ends of the shoulder blades fitting close to the spinal processes and ending some distance below the top of them. This junction should be so

FIG. 7.—A good type of dairy bull.

smooth as to form a straight line from the top of the spinal processes down the shoulder blade to its junction with the foreleg.

Body—Capacity.—Back: It is very important that there be great strength in this region, as the back supports the weight of the abdomen or barrel.

Ribs: Flat ribs are found to be associated with the wedge-shaped, lean appearance of the dairy animal as compared with the round ribs of the beef animal.

Barrel: The barrel, in both the male and the female, should be broad, deep, and full and well held up with well-sprung ribs. The barrel contains the stomach, liver, and intestines, the chief organs of digestion. A good-sized barrel indicates large capacity for digesting feed (fig. 8), one of the essential functions of the dairy cow. Although the barrel should be large, it should not sag away from the backbone into what is popularly called a "pot belly," leaving loose skin in the flank, nor swing when the animal walks. This indicates an objectionable weakness in the muscles of the abdomen, as these muscles should hold the barrel close up to the backbone.

Loins: The loins are that portion of the backbone just in front of a line drawn between the hip bones and extending forward to the beginning of the short ribs. The loins should be broad and strong. A sag or drop in this section of the back indicates weakness. A lack

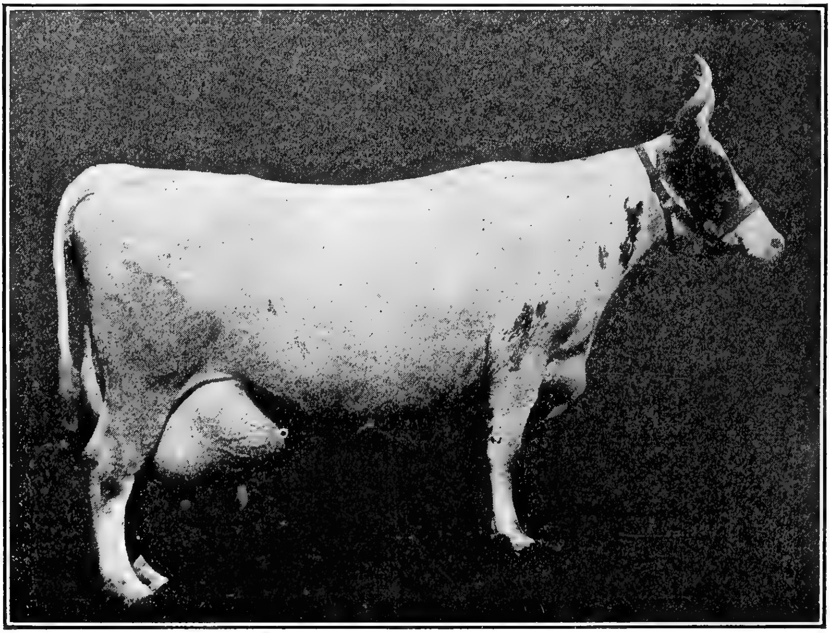

FIG. 8.—A large barrel indicates capacity for feed.

of width in this region is caused by short processes on each side of the backbone.

Hindquarters.—Hip bones: The hip bones should be wide apart and prominent.

Rump: The rump should be long, wide, and level. The length is measured from the hips to the pin bones. The rump is level when a plane passed through the top of the hip and pin bones is horizontal. A high pelvic arch is not desirable. The pelvic arch is inclosed by the spinal column and the pelvic bones. The joints of this arch constitute the hip and pin bones and this region contains the greater part of the reproductive organs in which the calf develops. It is asserted by some breeders that a short rump is associated with a short udder and a sloping rump with a sloping udder.

Pin bones: These bones are the parts of the pelvis which are located on each side of the tail. They should be prominent, widely spaced, and on a level with the hips. Low-placed pin bones are the cause of a sloping rump.

Thighs: The inner surface of the thighs should be thin and curved out so as to give ample room for the udder. Beefy, thick thighs are an objection, as they do not indicate specialization in the milk-producing function and do not give room for a broad udder.

Tail: The tail should be level in its attachment to the spinal column, small at this junction, and the bone should extend to the hocks: it should be thin throughout, and the switch long and fine.

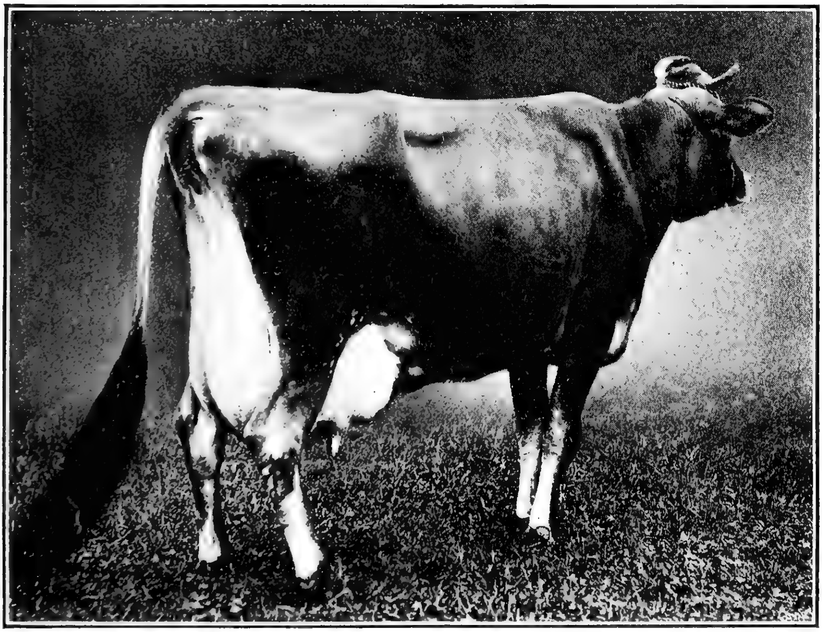

FIG. 9.—A well-developed udder.

Escutcheon: The escutcheon or "milk mirror" is the region above the udder between the thighs where the hair grows in a different direction.

Hind legs: The legs should be evenly and squarely placed on the body. The bones of the legs should be clean and close in texture. The joints should be ample in size to form leverages for the actions of the muscles, but they should be free from growths of any nature, either fleshy or cartilaginous. When the hocks are set farther back than the rear of the body they are described as sickle hocks.

The mammary system.—The mammary system is composed of the udder, teats, mammary or milk veins, and wells.

The udder: The udder should be large, wide, and have a long attachment to the body of the cow (fig. 9). In shape it should be somewhat rounding, with the lower part, floor, or sole of the udder as level as possible. The development should be symmetrical, so that the quarters are even in size. The more common defects in the udder are short attachment in front and low attachment behind; lack of width; sagging or pendulousness; a lack of uniform development, and fleshiness (fig. 10).

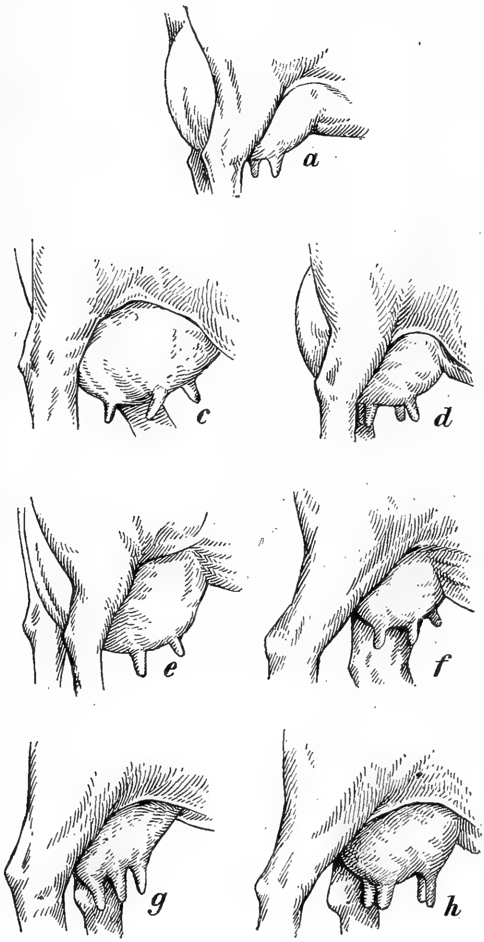

FIG. 10.—(a) Good type of udder; (c), (d), (e), (f), (g), and (h), poor types of udders.

Probably poor fore udders are as common as any other defect. Lack of development in this region causes a short udder attachment to the cow's body and very frequently accompanies a pendulent udder.

Pendulent udders indicate a short body attachment and a weakness of the muscular tissue which holds the udder to the body. Such udders are liable to bruise by swinging when the animal walks or runs, and also are in danger of being stepped on by the cow when she rises.

Three kinds of tissue go to make a cow's udder, namely, glandular, muscular, and fleshy. The first kind is the secreting tissue that produces the milk, and the more there is of it the better.

The function of muscular tissue is to support the udder and insure its firm attachment to the body. (Fig. 11.)

Fleshy tissue is undesirable in the udder and its presence indicates lack of quality and producing ability. Glandular tissue has a springy, elastic feeling and an udder in which this predominates collapses to a great extent when empty. On the other hand, when fleshy tissue composes a large portion of the udder, this latter is firm and does not collapse when empty. Considerable skill is necessary to determine the kind of tissue in the udder by the feeling;

the safer way is to have the cow milked dry and thus judge the character of the udder.

Teats: The teats should be of convenient size for milking, and should be evenly and squarely placed at the center of each quarter, so that the bottom will be in a horizontal plane and the distance equal between teats. They should be free from bunches either internal or external, and the sphincter muscles at the bottom of the teats should be rigid enough to prevent the leaking of milk but not stiff enough to cause difficult milking.

Mammary or milk veins and wells: The mammary veins are located on each side of the belly, extending from the udder forward

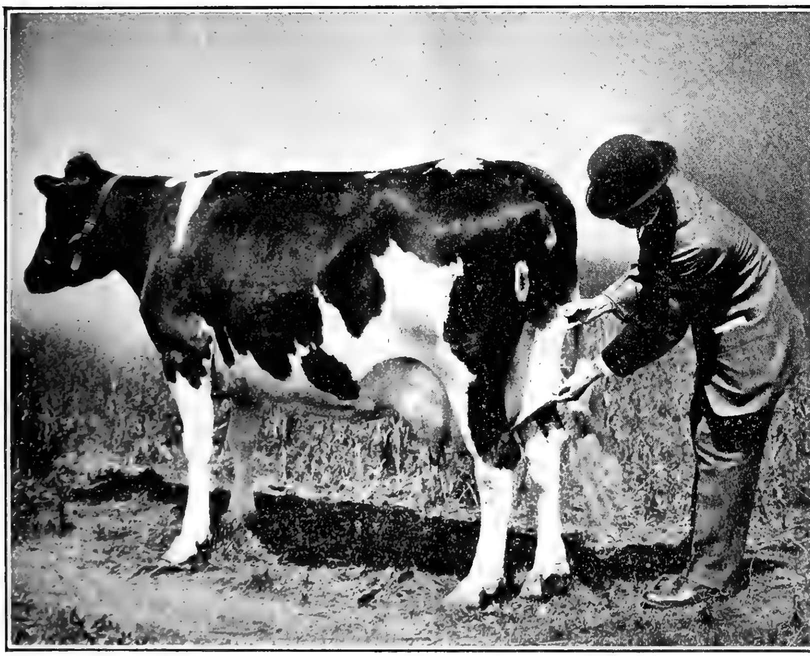

FIG. 11.—Udder attached well forward and well up behind and free from fleshiness.

toward the shoulders. They should be large, long, branching, and tortuous and should enter the abdomen well toward the shoulders. After that portion of the blood required for milk production is taken away the remaining portion returns to the heart through these veins. A large vein indicates that a great amount of blood is being returned to the heart and that consequently a large quantity of blood passed into the udder and was available for producing milk. In the heaviest milkers these veins are very crooked and often branching. In some cases they enter the abdomen through several openings on each side. The milk well, or the opening through which the vein enters the abdomen, should be large and well forward. (Fig. 12.)

PRACTICE JUDGING.

Preparing for a judging trip.—Exercises in stock judging, like other field trips, are often failures because proper preparation is not made for them. The teacher should know beforehand just where he is going and what he is going to do. The majority of secondary schools do not own a dairy herd, so that it is necessary for the class to make use of the cows belonging to neighboring farms. Arrangements should be made with the farmer so that there will be no misunderstanding upon taking the class to his premises. The teacher should select herds which contain animals suitable to his purpose and, as far as possible, select farms where conditions are favorable for judging. It is important to see that there are suitable inclosures and facilities for handling the animals. Cows should be selected which may be easily handled, especially for the first trip. If weather

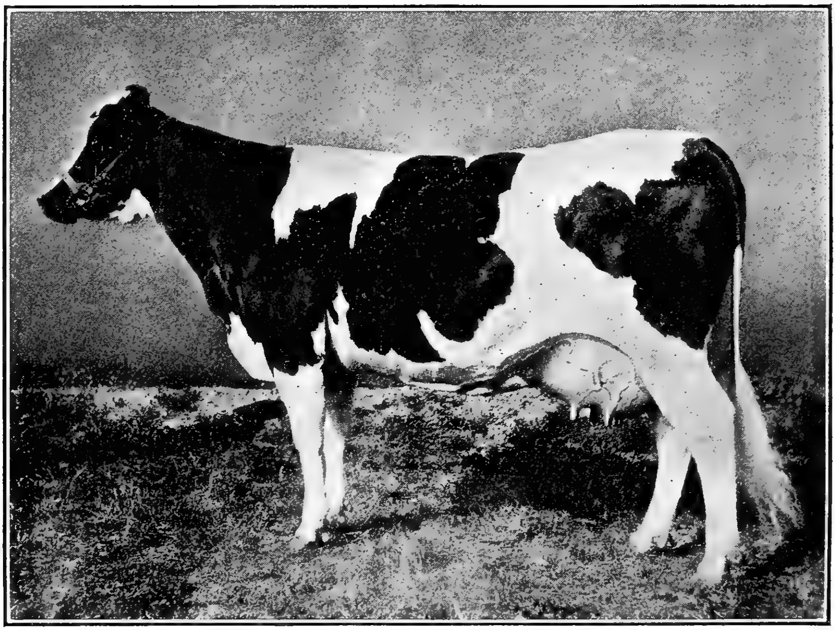

FIG. 12.—Prominent mammary veins.

is likely to be unfavorable, facilities for working under cover will be necessary. Wet, muddy barnyards are to be avoided. The instructor will find it to his advantage to examine thoroughly the animals he intends to use. When comparative judging is practiced it is especially important that the teacher be well acquainted with the animals and their relative points. The judging trip should be announced ahead of time so that all students may be prepared for outside work without delaying the class.

The first trip.—If the students have had no experience in judging cattle it will be well to use the first judging period in learning how to approach the animal, in checking up and applying what they have learned about naming the parts, and in going over the points of the card with the instructor. Boys may need caution that their approach to the animal may be quiet and friendly. Girls may need assurance that they may handle the animal without being harmed.

If possible, the animal chosen for the first lesson should approach the perfect dairy type, as it will aid in fixing that ideal in the minds of the students.

If the class has been studying the beef type and the students have had experience in judging cattle, the first period may be spent in comparing a dairy cow with a beef animal.

Scoring the dairy cow.—After the students have become familiar with the card and the method of approaching the animal they may make individual scores. The student should have well fixed in his mind at this time an ideal dairy form. The card will give the score for perfection in the various points; the student will enter a score which represents the points which he judges the animal to be worth. The sum of these points gives the score of the animal. It should be remembered that the use of the card is chiefly for the purpose of training the student in observation, so that no details should be omitted. The value of the card in judging animals depends largely upon the care with which it is used. It will be noted that the weights of different points vary greatly.

The scoring should be according to the following basis: 1.0, perfect; 0.9, very slight defect; 0.8, slight defect; 0.7, defective; 0.6, marked defect; and 0.5, poor.

The number of points given for any particular part of the animal should be multiplied by the classification of that point, in the mind of the student. For example, chest is assigned 8 points and the animal examined is found to be defective. Eight times 0.7 equals 5.6, which represents the final score for chest. In this manner the various parts of the body are scored in a proportional manner.

The value of accurate first impressions should be emphasized. As the student approaches the animal he is impressed at once by her temperament as indicated by her general shape and the development of her milk organs. An impression also as to her capacity and health will be evident. Observations should be taken from all sides of the animal, as development is not always uniform. Students should make an estimate of the cow's weight, and, if possible, their estimates should be compared with the weight as shown by the scales. A measuring tape will be useful at first in aiding the student to get proper ideas of proportions.

After the cow is sized up in a general way the student should proceed to go over her carefully point by point, commencing at the head and working in a systematic manner. Considerable attention should be given the barrel as an indication of capacity for feed, and the chest capacity as an indication of strong constitution. (Fig. 13.) Each student should feel of the skin and hair and observe the secretions in the ears. Special attention will be given the udder in its relation to milking capacity. Each student should examine carefully the mammary veins and milk wells. While it may not be possible for each student to assist in milking the cow, this feature of practical judging should be emphasized.

Students should work independently. Conversation and comparison of scores are to be avoided while the work is being done. The teacher should use his judgment in determining whether his time may be spent better in aiding the students or in scoring the animal as a basis for checking their results.

Checking results.—If time permits, it is well, while the animal is before the class, to compare the scores given and discuss its points. If there is no further time, the cards may be collected and graded by the teacher and then discussed at the next class. A thorough discussion of the score given will be very profitable. The teacher should not be arbitrary in his judgment, but should make allowance for a difference of opinion.

If the records of production are obtainable they may be used in checking the judgment of students as expressed in the scores given. Often the farmer, although he does not keep a record, has an accurate idea of the worth of his cow. The judgment of the student may be compared with the judgment of the farmer.

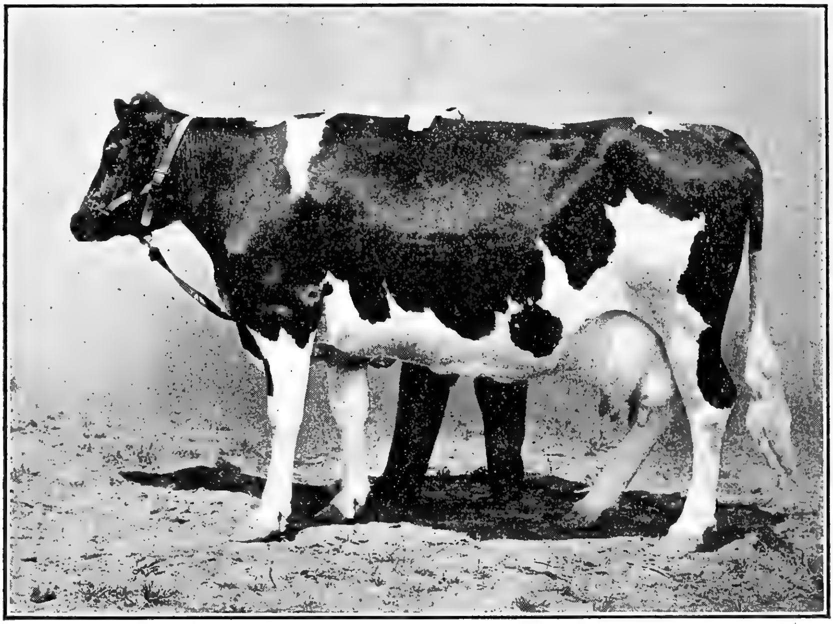

FIG. 13.—Large heart girth showing good chest capacity.

Comparative judging.—The scoring of animals is but preliminary to what is now considered to be the more efficient method of judging; that of comparison and placing according to merit. The student who has used the score card carefully with a number of cows should be prepared to take in the general conformation and detect the details which indicate the worth of the animal. In trying out the judgment of students in comparative judging, usually at first four cows, which have marked differences in ability, are chosen. As skill is developed animals more nearly equal may be chosen. It is well to have students study the market value of dairy cows in the district and place a money value on the cows judged. (Fig. 14.)

Reasons should be required for each placing. The form filled out below is suggested for this exercise. Each animal should be numbered or lettered.

Name of student, John Jones. Date, April 26, 1916.
Class of animals, Dairy cows.

Placing: First, B. Second, D. Third, A. Fourth, C.

1. I place B over D, because she approaches more nearly the ideal dairy form and has an udder of greater capacity, etc.

2. I place D over A, because she has greater chest capacity, indicating a stronger constitution, etc.

3. I place A over C, because she has a larger barrel, indicating a greater capacity for feed, etc.

Further practice with score card.—For later judging it will be well to select animals of varying ability as milk producers. If records may be obtained, it will be profitable to compare the scores given cows of good records with those whose records show they are poor producers.

A study of the dairy breeds usually follows the study of type. While all true dairy breeds are of the dairy type, there are minor differences which characterize each breed. (Fig. 15.) These breed characteristics are provided for in special score cards, which may be obtained from the breeders' organizations. Where several breeds are popular there will naturally be a good deal of breed comparison in the judging.

FIG. 14.—A difference in capacity of barrel.

Judging at fairs.—In some sections competitive stock judging at fairs and stock shows has become very popular. If these competitions are conducted with the student's development paramount, they have high educational value. Whether students enter a judging competition or not, the student of dairy husbandry can learn much at these shows. A progressive teacher will take advantage of live-stock exhibitions and will endeavor to organize the students and supervise their visit so that the best results may be obtained. The better fairs not only give the students an opportunity to see the best live stock of the section represented, but they also give them an opportunity to observe the methods of experienced judges. The work of the judges should be observed closely by the visiting class, and explanations of reasons for their placing carefully noted. The fairs give an opportunity for comparison of types and breeds which is seldom found in the school district.

At some of the schools local fairs are held in connection with the work in stock judging. A local exhibition of dairy cattle will aid in arousing interest in dairying and a desire for better stock, as well as give the students practice in judging. A program may be given in connection with the show. While men well qualified should give the main addresses concerning dairy cattle, a place should be re-

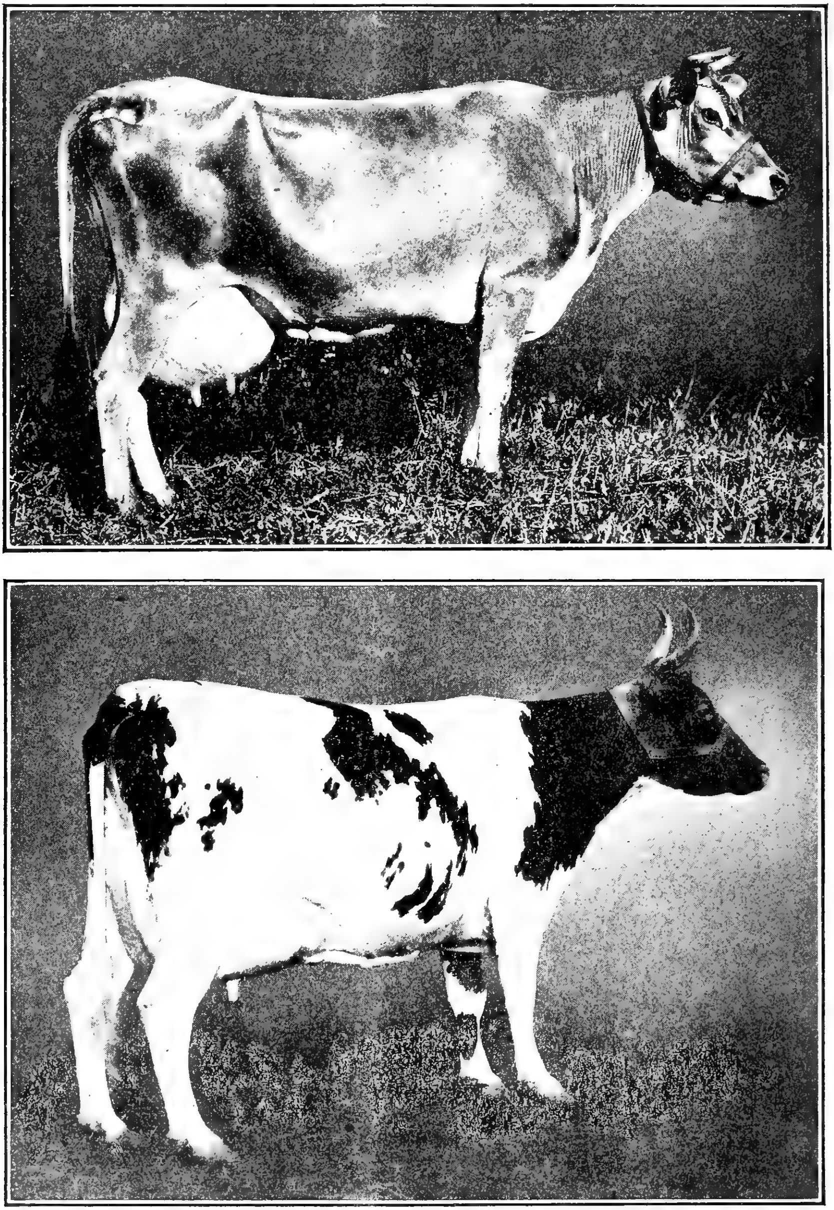

FIG. 15.—Dairy types of different breeds: (upper) Jersey; (lower) Ayrshire.

served for the members of the class. A debate on some question pertaining to type or breed of dairy cattle would be interesting as well as instructive.

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L. O. HOWARD, Chief.

Washington, D. C. ▼ November 25, 1916

THE APPLE LEAF-SEWER.

By B. R. Leach, *Scientific Assistant, Deciduous Fruit Insect Investigations.*

CONTENTS.

	Page.
Introduction	1
History	2
Distribution	2
Feeding habits and character of injury	2
Description of stages	4
Spring pupation of wintering larvæ	6
Emergence of moths	7
Oviposition of moths	8
Length of life of moths	8
Habits of moths	9
Incubation of eggs	9
Larval feeding period	10
Hibernation	10
Natural enemies	11
Remedial measures	11
Summary	12
Bibliography	13

INTRODUCTION.

In the summer of 1914, while engaged in deciduous-fruit insect investigations at Winchester, Va., the writer's attention was attracted by the common occurrence of the apple leaf-sewer, *Ancylis nubeculana* Clemens, sometimes termed the apple leaf-folder, upon apple foliage.

Although injury to apple foliage by the larva of this insect was recorded by Riley as early as 1877, very little concerning it has been published since. This apparent lack of attention may be attributed to the fact that although common and widely distributed, it has occurred so far only at infrequent intervals in sufficiently large numbers to cause serious damage and attract special notice to it, as an economic pest.

The feeding habits of the larva, while interesting when contrasted with those of other leaf-inhabiting species, are such as, under certain conditions, render the insect capable of considerable damage to the foliage of the apple, especially in young orchards receiving indifferent care. At the suggestion and under the direction of Dr. A. L. Quaintance, of the Bureau of Entomology, the study of the biology of this insect was made in the summer of 1914 and 1915.

Note.—This bulletin will be found of value to apple growers in the North and Central Atlantic States, the Middle West, and portions of Canada.

HISTORY.

This species was first described by Clemens, in 1860, under the name of *Anchylopera nubeculana* Clem. In 1875 Zeller described the adult, pupa, and larva under the name of *Phoxopteris nubeculana*. The first record of injury caused by this species is given by Riley, who called it by the common name of "apple leaf-sewer," in his annual report of 1878, the injury occurring in Ontario County, N. Y., where certain orchards were seriously affected, one-fourth of the leaves being infested. In 1878 P. H. Hoy reported it a serious orchard pest in Wisconsin, while Lugger, in 1899, reported injury by this insect in Minnesota. The moth has also been recorded as abundant in Ontario (Canada) orchards in 1895 and 1903. Felt in 1907 recorded the ravages of the insect in New York State and gave measures for its control. Slingerland and Crosby have given a short account of the apple leaf sewer in their recent "Manual of Fruit Insects."

DISTRIBUTION.

Dyar gives the distribution of this species as "North Atlantic States." Fernald received it from Nova Scotia (Canada), while Rounthwaite collected it in Manitoba and Fletcher recorded it from Ontario. In the United States, specimens in the United States National Museum, the correspondence, notes, and collection of the Bureau of Entomology, and the available literature, all indicate that this species occurs in the following States: Connecticut, Illinois, Maine, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, and Wisconsin.

FEEDING HABITS AND CHARACTER OF INJURY.

This insect appears to confine its attack to the apple.

Immediately on leaving the egg the larva migrates to the vicinity of one of the prominent main ribs on the underside of the leaf and spins a sheltering web of silk, under which it begins to feed (fig. 1, *b*). The larva never feeds before completing its shelter of silk, and during the first 3 or 4 weeks of its life does not leave this silken covering, but extends it from time to time over the tender parenchymatous tissue on the underside of the leaf, gradually drawing the lower sides of the leaf together (fig. 2). At the end of this period, the young larva, having increased very materially in size, gnaws through the upper tissues of the leaf and makes its way to a fresh leaf, usually the one directly above. Here it stations itself on the upper side of the leaf at the juncture of the midrib and stem and spins another web of silk. Each strand crosses the midrib at right angles, and both ends of each strand are fastened to the leaf at equal distances from the midrib. At the beginning, this web is about three-eighths of an inch in width and somewhat

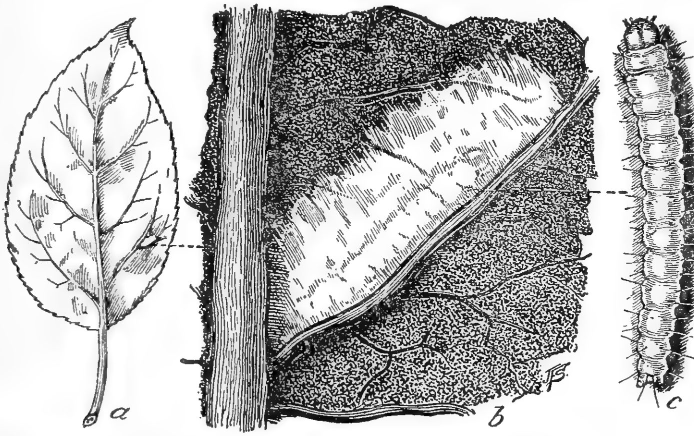


FIG. 1.—Apple leaf-sewer (*Ancylis nubeculana*): *a*, Apple leaf showing location of silken covering of newly hatched larva; *b*, portion of same, much enlarged; *c*, newly hatched larva, much enlarged. (Original.)

greater in length, but gradually the outer edges of the leaf are drawn together and at the end of 24 hours are completely joined (fig. 3, *a*).

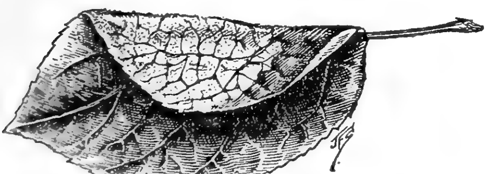


FIG. 2.—The apple leaf-sewer: Work of young larva on leaf. (Original.)

In constructing this web and weaving the strands of silk from the sides over the midrib, the larva appears to exert no force, and the drawing together of the upper sides of the leaf probably results from contraction of the silken strands in drying.

When the leaf has been folded in this fashion, the larva sews the two halves securely together with silk immediately under the edges. Within this folded leaf (see Pl. I, fig. 1) the insect continues to eat the upper parenchyma, the excrement being deposited within the fold near the stem end (Pl. I, fig. 3). The leaf soon begins to present a scorched appearance and the larva eventually gnaws a hole through the

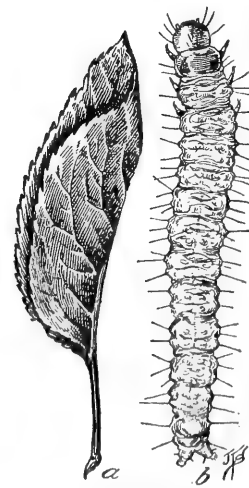


FIG. 3.—The apple leaf-sewer: *a*, Folded leaf showing how feeding larva is protected; *b*, full-grown larva, much enlarged. (Original.)

side (Pl. I, fig. 2) and, crawling to another leaf, repeats the folding and sewing operation.

During the season a single larva will thus destroy several leaves, and when the insect is present in sufficient numbers, extensive defoliation may result.

Felt, in discussing the habits of the apple leaf sewer or "folder," as he designates it, states that the common name "apple leaf folder" exactly describes the work of the caterpillar, since the presence of the dark yellowish-green, black-marked caterpillars is most easily recognized by the apposed halves of infested leaves, their edges being held together by strands of silk.

From observations made in the spring of 1915 it developed that the larva of the apple leaf-sewer does not begin to sew up the leaf immediately on leaving the egg, as stated by Riley, Felt, Fletcher, and others. This would seem an impossible task for the newly hatched larva because of its minute size.

DESCRIPTION OF STAGES.

THE EGG.

As far as can be ascertained, no description of the egg has been made in the literature of the apple leaf-sewer. This is probably due to the fact that the egg is minute, inconspicuous, and difficult to detect. Except in color, it bears a striking resemblance to the egg of the codling moth, being a flat, somewhat oval-shaped object with a raised circumference or flange and a shallow depression in the center (fig. 4, *b*). The eggs are about the size of pinheads, and are fairly uniform, averaging about 0.8 mm. in length and 0.6 mm. in width. The surface is covered with a network of ridges which are closer together and more regular toward the central portion than around the edges. When first deposited the eggs are the color of the leaf and it is only in reflected light that they can be detected. In 48 hours the color changes to a deep yellow. Later the embryo is indicated by the raised outer edge becoming darker in color, and shortly before hatching the larva is plainly visible, bent like a U around the central depression. The eggs are always securely glued

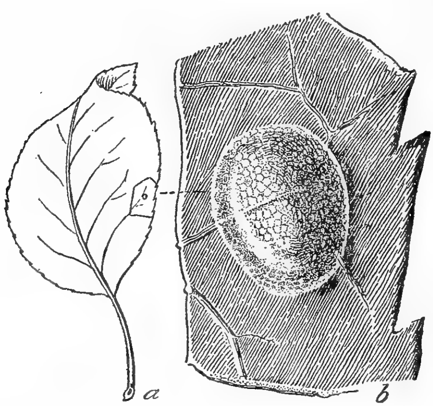
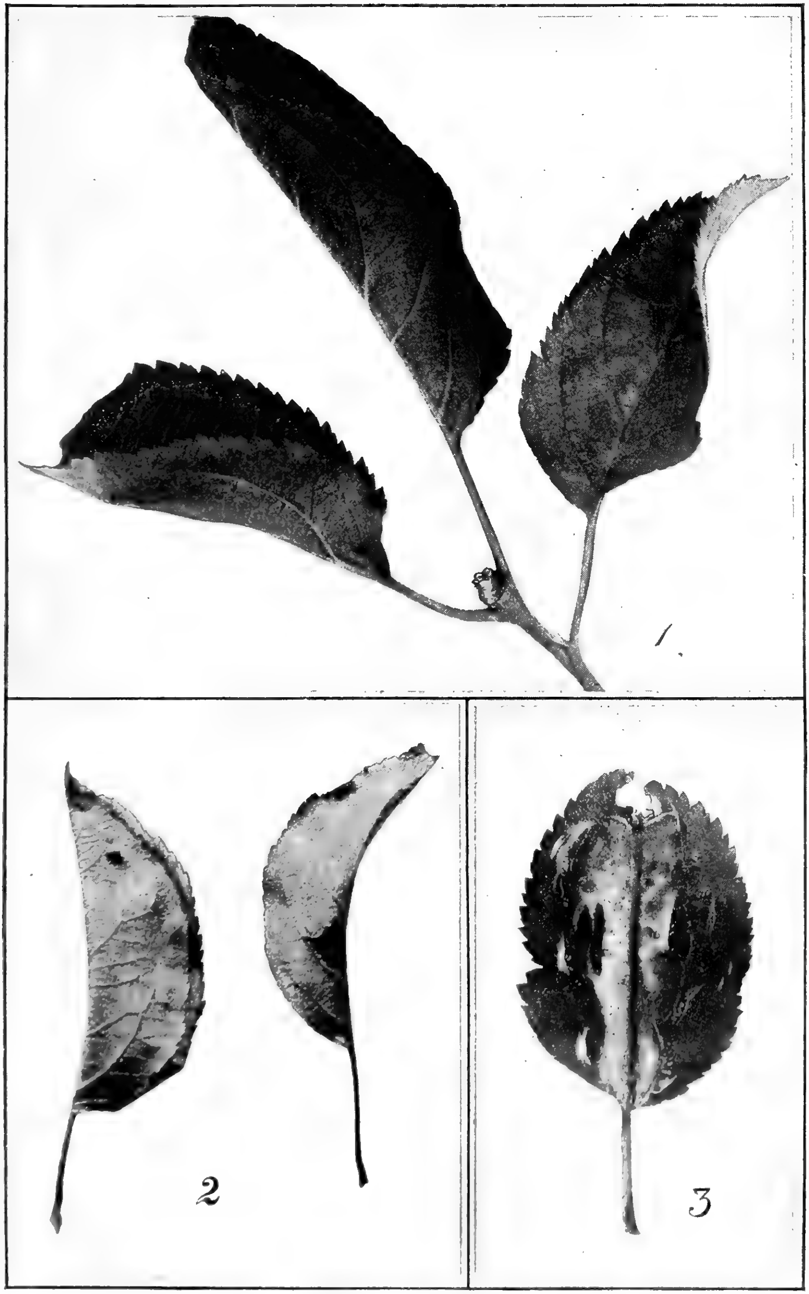


FIG. 4.—The apple leaf-sewer: *a*, Apple leaf, with position of egg indicated; *b*, egg on portion of leaf, greatly enlarged. (Original.)



THE APPLE LEAF-SEWER.

FIG. 1.—Twig bearing two leaves infested by the apple leaf-sewer (*Ancylis nubeculana*). FIG. 2.—Leaves killed by the apple leaf-sewer, showing exit holes of larvæ. FIG. 3.—Infested leaf torn apart, exposing larva, silken web, and partially destroyed parenchyma. (Original.)

to the leaf and are usually deposited on the under side, singly or in irregular groups (fig. 4, *a*). After hatching the eggshell is white and retains its shape. One often finds shells which remain for some time after the egg has hatched.

THE LARVA.

On hatching, the larva escapes through an irregular crack near the outer edge and leaves the eggshell in 2 or 3 minutes. The newly hatched larva is very active; its color is yellowish green throughout, with the exception of the orange-colored head. Riley describes the full-grown larva as follows:

> Length about 11.5 mm. Head a yellowish orange, thoracic shield yellowish, the body a variable fuscous yellowish green. The head is somewhat flattened, the labium reddish brown, the mandibles fuscous apically and the small antennæ are whitish basally, pale orange near the middle, and semitransparent apically. The large thoracic shield has irregular black markings at the lateral posterior angles, the body is somewhat more fuscous laterally, and the setigerous tubercles are rather large, lighter than the body, and each bears a single fuscous hair. Anal plate yellowish with a conspicuous irregular, transverse, black spot on the posterior half. True legs with the basal segment fuscous yellowish, the other segments dark brown or black, prolegs pale yellowish green.

There is great variation in the size and color of the larvæ, but the conspicuous black spots near each outer hind corner of the thoracic shield serve as a ready means of identification (fig. 3, *b*).

THE PUPA.

When first formed, the color of the pupa is a dark yellowish brown (fig. 5, *b*). The last four abdominal segments retain their original color, but the head, eyes, and wing shields gradually change to black, mottled with yellow. The wing shields extend to the fourth abdominal segment; the antennæ not quite so far. The anterior and posterior borders of each abdominal segment are armed dorsally with a transverse row of minute decurved spines. The anal segment is quite sharp. The size is variable and averages 3 mm. by 7.5 mm.

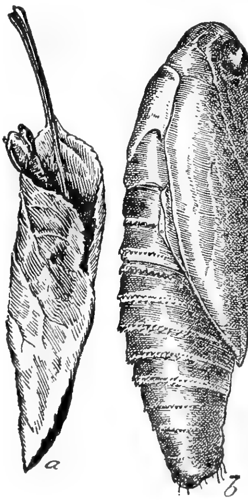


FIG. 5.—The apple leaf-sewer: *a*, Apple leaf showing pupal case and manner of emergence; *b*, pupa, much enlarged. (Original.)

THE ADULT.

The moth (fig. 6) measures about 18 mm. across the expanded wings. The head, thorax, and abdomen are dark brown dorsally and light gray upon the ventral side. The antennæ are dark brown, while the legs are light gray. The fore wings are marked by heavy white areas near the anterior margin and with a broad, oblique white stripe on the posterior margin near the extremity. The hind wings are light gray, merging into a somewhat darker gray at the outer margins.

FIG. 6.—The apple leaf-sewer: *a*, Adult moth, much enlarged; *b*, same, natural size, at rest. (Original.)

The adult was first described by Clemens in 1860. The following is his description:

Anchylopera nubeculana n. s. Fore wings white, with a dark brown dorsal patch extending from the base to the middle of the wing, with its costal edge irregular or doubly curved. The oblique central fascia is almost obsolete, except on the middle of the costa, where it appears as a dark grayish brown round spot exterior to which is a short black dash. The wing above the inner angle is varied with grayish brown and brownish. The costa exterior of the middle is alternately streaked with white and brownish, becoming reddish brown toward the tip. Extreme apex reddish brown.

SPRING PUPATION OF WINTERING LARVÆ.

At Winchester, Va., in the spring of 1915, pupation of the wintering larvæ began the latter part of April, and from that time pupation appeared to depend entirely on the temperature. A few days of warm weather would result in several larvæ entering pupation, while a cold spell would prolong that period for those already in pupation and prevent any additional larvæ from transforming. In the latitude of northern Virginia and the District of Columbia pupation evidently begins normally about April 20, or possibly a little before, depending on the relative lateness of the season.

The larvæ used in obtaining these pupation records were collected in November, 1914, shortly before the leaves began to drop. They were placed in rearing jars partly filled with soil and carried through the winter in an out-of-doors rearing shelter. The beginning of pupation was readily observed, since the larva pupates within the folded leaf in which it undergoes the final molt.

TABLE I.—*Length of pupal period of wintering larvæ of the apple leaf-sewer, Winchester, Va., 1915.*

No. of observation.	Date of— Pupation.	Date of— Emergence of moth.	Length of pupal period.
			Days.
1	Apr. 19	May 13	24
2	Apr. 21	...do....	22
3	Apr. 22	May 15	23
4	May 4	May 26	22
5	...do....	May 27	23
6	...do....	May 28	24
7	...do....	June 1	27
8	May 8	June 4	27
9	...do....	June 6	29
10	...do....	...do....	29
11	...do....	June 3	26
12	May 9	June 8	30
13	May 11	June 7	27
14	...do....	...do....	27
15	...do....	June 8	28
16	...do....	June 7	27
17	May 12	June 8	27
18	...do....	...do....	27
Max			30
Min			22
Av			26.05

The longest pupal period observed was 30 days, the shortest 22 days, and the average of the 18 observations 26.05 days. The records at Winchester show a much longer duration of this stage than has been observed by others, though data from other sources are rather limited. Johannsen, in 1909, states that in Maine the larvæ transform to chrysalids during April and that about 10 days later the moths begin to appear.

EMERGENCE OF MOTHS.

Table I gives the time of appearance of moths that emerged at Winchester in the spring of 1915 from field-collected rearing material, with the exception of the first adult, which appeared in the laboratory on May 7, and upon which no pupal record was obtained. The main emergence, however, did not begin until the latter part of May.

As before stated, pupation takes place within the folded leaf. When ready to emerge the pupa forces its body through the edges or some convenient crevice of the folded leaf until about half the body is projected. The moth then emerges, crawls about upon the dead leaf, and holds the wings over the head to dry, leaving the discarded pupal skin hanging through the leaf (fig. 5, *a*). The moths emerge during the early hours of the morning, several having been observed drying their wings at that time.

The moth is extremely difficult to detect in the orchard, but on three separate occasions, May 27, June 3, and June 6, adults were captured in the field, which verifies to some extent the emergence period observed in the laboratory.

OVIPOSITION OF THE MOTHS.

As the moths emerged from day to day they were transferred to rearing jars containing apple twigs in leaf, the ends of which were placed in small vials of water to maintain freshness. The eggs are laid singly or in irregular groups, usually on the underside of the leaf, but sometimes on the upper side, and are securely glued to the leaf; in fact, they can not be removed without crushing. In the rearing cages the eggs are often deposited indiscriminately upon the sides and bottom of the jars.

TABLE II.—*Oviposition of moths of apple leaf-sewer, Winchester, Va., 1915.*

Number of cage.	Number of moths.	Date of—			Days.		
		Emergence.	First oviposition.	Last oviposition.	Before oviposition.	Of oviposition.	From emergence to last oviposition.
1	3	June 1	June 2	June 7	1	6	7
2	4	June 6	June 7	June 11	1	5	6
3	3	June 7	June 9	June 19	2	11	13
4	4	June 8	...do....	June 21	1	13	14
Maximum					2	13	14
Minimum					1	5	6
Average					1.25	8.75	10

From Table II it will be seen that the moths begin to deposit eggs in from 1 to 2 days after emergence, the average for 4 observations being 1.25 days. The average period of oviposition lasted 8.75 days, the longest period observed being 13 days and the shortest 5 days.

While these observations show that the moths oviposit very shortly after emerging, Johannsen, in 1909, states that in Maine moths appear in April and deposit their eggs in June.

Copulation has not been noted, but occurs very soon after emergence, as indicated by the short period between emergence and oviposition.

No individual egg-laying records were obtained, but in confinement the moths averaged about 65 eggs each.

LENGTH OF LIFE OF MOTHS.

The length of life of 11 adults is given in Table III.

TABLE III.—*Length of life of moths of apple leaf-sewer, Winchester, Va., 1915.*

Number of moths.	Length of life.	Number of moths.	Length of life.
1	5	1	15
2	8	1	15
1	10	1	17
1	12	1	18
2	14		
Total		11	114
		Maximum	18
		Minimum	5
		Average	10.3

These moths were supplied with honey and water. Several moths were given no food or water and several were given water alone. The former lived only a few days after emergence and the latter lived a shorter period than those supplied with both water and honey.

The moths fed upon water and honey lived from 5 to 18 days, the average of 11 observations being 10.3 days. No data were obtained upon the relative longevity of the sexes.

HABITS OF MOTHS.

The moths are active during the day, especially in the morning, at which time they appear to deposit most of the eggs. In the rearing cages they are rather inactive, spending most of the time resting on the underside of the leaves, with their wings tightly folded (fig. 6, *b*). In the orchard they are active, making short, quick, erratic flights from one portion of the tree to another. The moths are so small and so adept at hiding that they are seldom observed in the orchard.

INCUBATION OF EGGS.

The shortest incubation period observed was 7 days, the longest 13 days, and the average for 16 lots of eggs 8.8 days. As a rule, the incubation period for the individual eggs of a given lot varied only a few hours, and in recording observations for any lot of eggs incubation was considered over when the first egg hatched. Table IV shows the incubation period of the eggs.

TABLE IV.—*Incubation period of eggs of apple leaf-sewer, Winchester, Va., 1915.*

Number of eggs observed.	Date— Deposited.	Date— Hatched.	Period of incubation.
			Days.
25	June 2	June 15	13
6	June 5	June 14	9
13	June 6	June 15	9
24	June 7	June 16	9
53	June 8	June 17	9
52	June 9	...do...	8
39	June 11	June 18	7
62	June 12	June 19	7
41	June 13	June 20	7
48	June 14	June 22	8
23	June 15	June 23	8
17	June 16	June 25	9
28	June 17	June 26	9
21	June 18	June 25	7
5	June 19	June 30	11
5	June 21	July 2	11
Average			8.8

LARVAL FEEDING PERIOD.

As fast as the larvæ hatched in the laboratory they were transferred to the leaves of young trees growing within cages of wire netting. When placed upon the leaf the newly hatched larva immediately crawled to the underside of the leaf and began the construction of its silken web, as previously described. About this time (June 24) young larvæ were very abundant in the young unsprayed orchards in the vicinity of Winchester, Va. During the remainder of the summer the larvæ continued to feed upon the leaves, the length of the feeding period therefore being directly dependent on the time the individual infested apple leaves begin to drop in the fall. The leaves infested by the apple leaf-sewer usually fall before the rest of the normal foliage, owing to their weakened condition. In 1914 the leaves continued upon the trees until about November 20, while in 1915 they had all fallen to the ground by November 6. Table V shows the feeding period of the larvæ.

TABLE V.—*Feeding period of the larvæ of the apple leaf-sewer, Winchester, Va., 1915.*

Number of individuals.	Date— Began feeding.	Date— Leaf dropped.	Number of days feeding.
1	June 15	Nov. 3	141
1	June 16	Nov. 1	138
1	June 17	Oct. 30	135
1	June 18	Oct. 31	135
1	June 19	Nov. 6	140
1	June 20	Oct. 31	133
1	June 22	Nov. 5	136
2	June 23	...do....	135
2	June 25	Nov. 1	129
1	June 26	Nov. 2	129
1	June 30	...do....	125
2	July 2	Nov. 4	125
Total. 15			
	Av......	....	132.66
	Max....	....	141
	Min.....	....	125

The shortest feeding period was 125 days, the longest 141, while the average for 15 observations was 132.66 days. The leaves become dry and hard within 2 or 3 days after falling. The feeding period of the individual larva was therefore considered as completed when the leaf infested by it had fallen from the tree.

HIBERNATION.

When the folded leaf containing the larva falls to the ground in the late fall, the larva lines the inside of the folds with silk and hibernates until spring. Experiments indicate that the larvæ hibernating in the fallen leaves are able to withstand great extremes of moisture and temperature conditions, and that a larger proportion of them successfully withstand the winter than would ordinarily be supposed.

NATURAL ENEMIES.

The larvæ of *Ancylis nubeculana* are attacked by a number of parasitic and predacious enemies.

Pseudomphale ancylae Girault, n. sp. [MSS.], a hymenopterous parasite belonging to the family Chalcididae, was found to be a very common enemy of larvæ of the apple leaf-sewer in the vicinity of Winchester, Va. Six hundred and seventy-eight infested leaves were collected in the fall of 1914, and of these, 98 contained the pupal cases of this parasite, indicating that about 15 per cent of the leaf-sewer larvæ were destroyed. In late summer and early fall the parasitic larvæ leave the body of the host and spin their cocoons within the folded leaf, attaching the cocoons along the midrib of the leaf. From 4 to 6 parasites emerge from a single leaf-sewer larva. Only in two instances on examination at this time were pupæ found in these cocoons, and it appears that the parasite does not commonly overwinter within the folded leaf.

No parasites were reared from the breeding material in the spring of 1915.

Riley reared a braconid, *Rhysipolis phoxopteridis* Riley MS., from a leaf-sewer larva, in 1884, at Kirkwood, Mo., and in 1877, at Ithaca, N. Y., reared *Angitia paediscae* Riley MS.

Ants are an important factor in reducing the number of larvæ and pupæ during the winter and spring. In the spring of 1915, during the pupal period, ants almost ruined the writer's breeding material, which had been placed upon the ground under wire rearing cages.

REMEDIAL MEASURES.

The apple leaf-sewer larva migrates from one leaf to another several times during the season, which renders the control of this insect by the use of arsenical sprays very simple. According to the life-history studies of this insect at Winchester, Va., in 1915, the eggs begin to hatch about June 14 and continue hatching until about July 2, the maximum number of larvæ appearing about June 20. *The regulation arsenical spray of 2 pounds arsenate of lead to 50 gallons of water, applied by June 15, will therefore control this insect, and as the second spray for the first brood of codling moth is usually applied by the above date, in the vicinity of Winchester, no special application will be required for the control of the apple leaf-sewer.*

Spraying experiments conducted at Winchester, Va., indicate that even the full-grown larva is extremely sensitive to arsenical sprays and readily killed by that means. This is easily understood when one remembers that on sewing up the leaf the larva consumes all the upper parenchyma and can not escape the arsenate of lead deposited thereon by the spray.

In Virginia young apple trees which do not receive the arsenical spray are frequently defoliated by the apple leaf-sewer, whereas neighboring orchards in bearing, having received one or more codling-moth spray applications, almost entirely escape. Young orchards should receive the arsenical spray as soon as this pest appears in numbers sufficient to cause any serious damage.

Mr. Fred Johnson [1] describes conditions in Niagara County, N. Y., in 1905, as follows:

> The depredation of this pest is becoming quite marked in many orchards in the Youngstown district and also in orchards on the Canadian side of the Niagara River. The worst infestation coming under my notice is in an orchard of about 60 acres of the Greening, Baldwin, and Duchess of Oldenburg varieties.
>
> On many of these trees nearly all the leaves are sewn together and have a scorched appearance. The larva does not appear to attain its full growth in one leaf, but as soon as it has eaten the greater part of the tissue on the inside of the leaf which it has sewn together it gnaws a hole through the side of the leaf and escapes. It then attacks another leaf and proceeds as with the one it has vacated.
>
> This entire orchard is in sod and received only an indifferent spraying early in June. Parts of trees and whole trees that were fairly well sprayed have good foliage, whereas the foliage of trees or parts of trees which received little or no spray has either fallen or presents a scorched appearance on the tree.
>
> Duchess of Oldenburg trees sprayed June 9 and June 23 with 4 pounds of arsenate of lead to 50 gallons of full-strength Bordeaux mixture are quite free from this pest, whereas its ravages on the check trees are very marked. The condition of the foliage in this orchard at this date indicates that the pest can be held in check by thorough spraying at the dates that applications are usually made for scab and codling moth.

Mr. Johnson used 4 pounds of arsenate of lead to 50 gallons of water, but the spraying experiments conducted at Winchester, Va., indicate that 2 pounds of arsenate of lead to 50 gallons of water is sufficient for the control of the apple leaf-sewer. Lime-sulphur solutions or Bordeaux mixture may or may not be added, according to orchard conditions.

SUMMARY.

When present in sufficient numbers, the apple leaf-sewer may cause serious injury to apple foliage.

The apple leaf-sewer is generally distributed over the North and Central Atlantic States, the Middle West, and in portions of Canada.

The insect appears to confine its attack to the apple.

The newly-hatched larva spends the first 3 or 4 weeks of its life under a silken covering on the underside of the leaf. The remainder of the larval feeding period is passed within a succession of folded leaves. It destroys these leaves by eating the upper parenchyma.

In appearance the egg is very similar to that of the codling moth. The average period of incubation was found to be 8.8 days.

The full-grown larva is yellowish green, with an orange-colored head and thoracic shield, the latter with irregular black markings

[1] Unpublished notes, Bureau of Entomology.

at the lateral posterior angles. This last character serves as a ready means of identification.

The larval feeding period varies from 125 to 141 days.

The larva hibernates upon the ground within the fallen leaf, and while in this state is able to withstand wide extremes of moisture and temperature.

When first formed the pupa is a dark yellowish brown, some portions later changing to black, mottled with yellow.

The moth is grayish brown and measures about 18 mm. across the expanded wings.

In the latitude of northern Virginia, in a normal season, pupation begins about April 20, or possibly a little before, depending on the relative lateness of the season. The larva pupates within the folded leaf upon the ground. The average pupal period of the wintering larva of the apple leaf-sewer at Winchester, Va., in 1915, was 26.05 days.

In 1915, the moths continued to emerge from May 7 until June 8. They began to deposit eggs upon the apple foliage in from one to two days after emergence. Oviposition lasted from 5 to 13 days, and the moths averaged 65 eggs each. They lived from 5 to 18 days, averaging 10.3 days.

The moths are active during the day, especially during the morning, at which time they appear to deposit most of their eggs.

The principal insect enemy of the apple leaf-sewer in Virginia appears to be *Pseudomphale ancylae* Girault, n. sp. [MSS.], of the family Chalcididae.

At all times during the larval stage, the apple leaf-sewer is very susceptible to arsenical sprays. Arsenate of lead should be used at the rate of 2 pounds to 50 gallons of water. Bearing orchards receiving the customary spraying for the codling moth usually escape injury from the apple leaf-sewer. Young orchards should receive an arsenical spray as soon as the insect appears in numbers sufficient to cause serious damage.

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BULLETIN No. 436

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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THE DESERT CORN FLEA-BEETLE.

By V. L. WILDERMUTH, *Entomological Assistant, Cereal and Forage Insect Investigations.*

CONTENTS.

	Page.		Page.
Introduction	1	Life history and habits	7
Distribution	2	Seasonal history	15
Economic considerations	2	Natural enemies	16
Food plants	4	Remedial and preventive measures	18
Descriptions	5	Summary	21

INTRODUCTION.

For a number of years past reports have been received by the Bureau of Entomology of considerable damage to corn, milo maize, and related crops by a small black beetle, *Chaetocnema ectypa* Horn, which, because of the fact that it is a native of the southwestern desert regions, has been named the desert corn flea-beetle (fig. 1, p. 5).

The writer first noted this small black beetle in the spring of 1910, while located on a ranch in the extreme southern part of California. In a field which had been planted to Indian corn, as an experiment on the productiveness of this corn in the newly irrigated Imperial Valley, it was noticed that within a few days after the corn came through the ground the leaves became whitened and bleached, apparently as a result of the work of some insect, and upon closer investigation this beetle was found to be the cause. Subsequently the work of this flea-beetle was noticed on various Egyptian corns and sorghums as well as on sweet corn in various localities, not only in southern California but also in southern Arizona and New Mexico.

The study of the habits, life history, and methods of controlling this insect was commenced in the Imperial Valley of California in 1910, and during 1913, 1914, and 1915 has been conducted at Tempe, Ariz.[1]

The following pages comprise a report of these studies and observations upon the economic status of this species in the Southwestern States.

[1] The writer was assisted during a part of the time by Messrs. R. N. Wilson, F. H. Gates, and L. J. Hogg, of the Bureau of Entomology.

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DISTRIBUTION.

So far as known, the distribution of this flea-beetle is confined to those areas of the southwestern United States that are normally semiarid in climate. As was stated in a preceding paragraph, the observations by the writer and his associates have been confined to California, Arizona, and New Mexico, and the species has been collected in practically all of the lower altitudes throughout these States. Collections in the higher altitudes show the species to be usually absent. This is no doubt due to the annual rainfall, which usually increases with the altitude. An exception to this rule, however, was found by Mr. F. H. Gates, during the fall of 1915, when he took several of the adult beetles at Prescott, Ariz., elevation 5,000 feet, where they were injuring Sudan grass. The writer, three months previous to this, had made observations throughout northern Arizona, stopping at Kirkland, Prescott, Ash Fork, Flagstaff, Holbrook, Williams, and Joseph City, all of which are located at altitudes over 3,000 feet, and although a careful and prolonged search was made upon various known food plants, not a specimen was found and no injury was apparent except at Prescott, where typical feeding scars were found on corn.

Through the kindness of Dr. F. H. Chittenden, the writer was permitted to make use of certain records in the files of his office and found that Prof. E. S. G. Titus had collected the species upon sugar beets at Lehi, Utah, and Huntington Beach, Cal.; that Mr. E. L. Crow found specimens at Yuma, Ariz.; and that Mr. H. O. Marsh collected specimens feeding upon corn at Anaheim, Cal.; the type specimens were secured at Los Angeles, Cal., and Dr. George H. Horn reported it as also occurring in Arizona. Only one other observation has apparently been recorded;[1] this was by Dr. A. W. Morrill, who mentions it as occurring upon Sudan grass at Phoenix, Ariz.

ECONOMIC CONSIDERATIONS.

To understand properly the nature of insect damage to crops growing on irrigated tracts in the southwestern semiarid regions of the United States one should know something of the existing conditions. A tract of land is often found, varying from 200 to 100,000 acres or more, entirely surrounded by thousands of acres of land which is practically worthless from an agricultural standpoint; yet growing upon this land are weeds and grasses which serve as the native food plants for certain insects. When this comparatively small irrigated or dry-farm tract is planted to any crop, such as corn, milo maize, Kafir corn, etc., a great many of these insects quickly attack the new growing crops and feed upon them. Then, when

[1] Morrill, A. W. Report of the entomologist of the Arizona Commission of Agriculture and Horticulture. Ariz. Com. Agr. Hort., 6th Ann. Rpt., p. 33, 1914.

these crops follow one another year after year, and the area becomes established and known as a farming region, the insects develop in still larger numbers, being fostered by abundant food and protected by certain careless methods of farming. Sooner or later we have an economic pest of grave importance.

The injury caused by the flea-beetle under discussion is due to just such circumstances, and to these alone.

As has been suggested previously in this paper, this insect does its greatest injury to Indian corn of various kinds and to the non-saccharine sorghums, while it bids fair to be a very important pest of Sudan grass. It also exerts a minor influence upon all crops on which it feeds, taking its yearly toll from each of them.

NATURE OF INJURY.

In destroying its food plant, this beetle works from both ends, as it were, the adults attacking the plant above the ground and the larvæ below the ground. The adults eat out the chlorophyll of the leaves, and when sufficiently numerous they cause the leaves to wilt. If feeding is long continued, new growing plants will be killed. As the eggs are deposited below the surface of the ground, the larvæ immediately begin feeding upon the roots, and soon the plant has quite a shallow root system that will not support it in a thrifty manner.

The roots, after having been injured by the larvæ, attempt to overcome this injury by sending out new laterals, as illustrated in figure 6, page 11, and then sometimes slight windstorms will cause plants to blow over and lodge badly, thus further reducing the yield.

EXTENT OF INJURY.

The extent of damage inflicted in any year upon any particular crop depends largely upon conditions. First, if corn is planted early in the spring, it will usually suffer most heavily. Then again, if the grain is planted under conditions which have been ideal for the hibernation of adult beetles, the damage will also be considerable. In the early months of the year sweet corn is especially liable to attack, and partly because of this it is almost impossible to secure roasting ears early.

Mr. Peterson, of the Bureau of Plant Industry, who was formerly in charge of the experiment station located at Bard, Cal., states that these beetles damage corn on the station plats to a considerable extent, and that they have caused this damage there for several years. The writer has seen small pieces of corn completely destroyed by this beetle, the attack occurring just as the corn was coming through the ground. In these cases the owner often thought that the corn had failed to come up.

Mr. R. N. Wilson, in notes made during May, 1912, at Sacaton, Ariz., relative to a small area cultivated by the Pima Indians, stated that corn on the Bureau of Plant Industry Experimental Farm at that place had been entirely killed by these beetles before it matured. Mr. Hudson, agent in charge of this farm, says that this is the usual fate of the early corn planted at Sacaton, but that some years the beetles are not so numerous and the corn partially escapes, although it is not so vigorous as it should be, on account of the beetle attack.

Three years previous to this, Mr. C. N. Ainslie, also of the Bureau of Entomology, made the following notes on his observations in the same locality:

> Heard early this a. m. that a "black bug" was destroying corn in garden. Found several long rows of corn 4 to 6 inches high, almost killed by *Chaetocnema ectypa*. The beetles were clustered on the leaves and in many cases a dozen or more would be down in the center, busy with the terminal leaf. The hills looked as if blasted by a hot wind.
>
> Some volunteer stalks of corn 2 feet high, in a watermelon patch some rods away, were bleached almost white, as was a plat of corn 2 feet high on experimental plat, 60 rods or so distant. These beetles are credited with doing much mischief to corn here.

Dr. A. W. Morrill [1] states:

> The corn flea-beetle, *Chaetocnema ectypa*, was unusually abundant in parts of the Salt River Valley, and was especially troublesome in experimental plots of Sudan grass at the experiment station farm near Phoenix.

Prof. G. F. Freeman,[2] of the University of Arizona Experiment Station, in speaking of variety tests of Papago and other varieties of sweet corn, says:

> Small black flea-beetles (*Chaetocnema ectypa*) injured both lots quite severely. So many plants of the early lot at Tucson were killed that all plots had to be replanted about April 20. The latter planting was injured to some extent but very few plants were killed outright.

From these observations it is obvious that the injury caused by this beetle is such as to demand careful attention, and vigorous efforts should be made to reduce its numbers upon the ranches of the southwestern United States.

FOOD PLANTS.

It seems probable that this beetle had as its native food plant some one or more of the native grasses growing in the Southwestern States, as it is found on quite a number of these. It is especially abundant at different times on wild barley (*Hordeum murinum*), salt grass (*Distichlis spicata*), Johnson grass (*Sorghum halepense*), and hair-grass dropseed (*Sporobolus airoides*), as well as on others. Johnson grass and salt grass are two of its favorite food plants, and at all

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[1] Morrill, A. W. Report of the entomologist of the Arizona Commission of Agriculture and Horticulture. *In* 6th Ann. Rpt. Ariz. Com. Agr. Hort., p. 33. 1914.

[2] Freeman, G. F. Papago sweet corn, a new variety. Ariz. Agr. Exp. Sta. Bul. 75, p. 462. May, 1915.

seasons of the year when these grasses are flourishing the adult beetles can be found feeding upon the leaves, while the larvæ can be taken from the roots.

Of the cultivated crops, this beetle seems to be especially fond of corn, milo maize, and Sudan grass, and it is to these crops that it does the greatest damage. It has been taken in both the adult and larval stages, feeding upon Indian corn, milo maize, kafir corn, sorghum, sugar cane, Sudan grass, wheat, barley, and alfalfa, and Mr. R. N. Wilson reported it as doing exceedingly great damage to a field of beans on a ranch southeast of Tempe, Ariz. According to the statement of Mr. E. W. Hudson, many young bamboo plants growing on the Bureau of Plant Industry Experimental Farm at Sacaton, Ariz., were entirely killed. Dr. F. H. Chittenden has on file a record by Mr. E. L. Crow, showing that the beetle, besides feeding on corn, Johnson grass, and barley, occasionally attacks cantaloupes; and one by Mr. E. S. G. Titus, reporting it as feeding upon sugar beets

DESCRIPTIONS.

THE ADULT.

One is hardly likely to confuse this flea-beetle with any other occurring in the areas where corn, wheat, barley, and Sudan grass are seriously injured. Only one other resembling it in size, color, and jumping habits occurs in these semiarid regions in any number. This is the western cabbage flea-beetle (*Phyllotreta pusilla* Lec.) which occurs on cruciferous plants, and which differs in being slightly longer

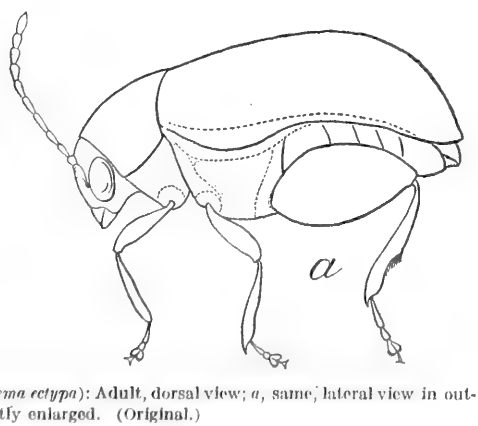

FIG. 1.—The desert corn flea-beetle (*Chaetocnema ectypa*): Adult, dorsal view; *a*, same, lateral view in outline. Greatly enlarged. (Original.)

and in having a more pointed abdomen than the desert corn flea-beetle. The eastern corn flea-beetle (*Chaetocnema pulicaria* Crotch) occurs in exceedingly limited numbers in the southwestern United States, but the farmer need not be concerned in regard to this, for the insects are quite similar in habits and methods of control.

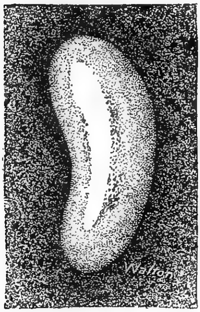

FIG. 2.—The desert corn flea-beetle: Egg. Greatly enlarged. (Original.)

The adults of *Chaetocnema ectypa* (fig. 1) are shining black, less than 2 millimeters (three thirty-seconds of an inch) in length, and nearly as broad as long. Upon a corn leaf they appear as tiny, nearly round objects, each about the size of the point of a lead pencil. The species was originally described by Dr. George H. Horn in 1899. His description is necessarily incomplete, since he merely points out the difference existing between *Chaetocnema ectypa* and *Chaetocnema obesula* Lec., which it very closely resembles. The description follows:

Surface distinctly aeneous. Antennae rufotestaceous at base, the five outer joints piceous. Thorax distinctly alutaceous. The punctation extremely fine, indistinct, and sparse. The basal marginal line consists of fine, closely placed punctures. Anterior and middle femora brown, the posterior femora piceous, tibiæ and tarsi rufotestaceous. Length, 0.06 inch; 1.5 mm.

THE EGG.

The eggs (fig. 2) are minute, averaging about 0.35 mm. long by 0.15 mm. in diameter, whitish and invisible to the unaided eye unless placed upon a suitable dark or black background. They are bean shaped, with one side slightly concave and one end smaller than the other. The surface is sculptured and of a creamy white luster, which becomes apparent when the egg is examined with a binocular microscope.

THE LARVA.

The larvæ (fig. 3) of this flea-beetle are elongate and quite small in diameter; compared to the adult, they seem to be the young of a larger insect. When newly hatched they are very small and delicate, being less than a millimeter in length; the measurements of six specimens giving 0.80 mm., 0.75 mm., 0.70 mm., 0.75 mm., 0.80 mm., and 1.10 mm., they being eight times as long as their greatest diameter. The head plate measures 0.1 mm. in width. They are pale white excepting the head, which is a very light straw color, and are

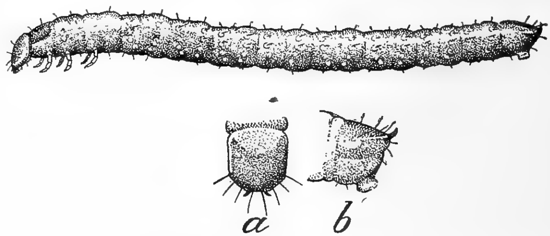

FIG. 3.—The desert corn flea-beetle: Larva; *a*, anal segment, dorsal view; *b*, same, lateral view. Greatly enlarged. (Original.)

partially covered with short stiff hairs. In color and texture they are so much like the corn roots in which they are found feeding that one will often overlook a larva, even with the aid of a microscope. However, when quite numerous, the full-grown larvæ are easily found on the roots of a corn plant or in the surrounding soil.

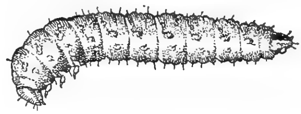

FIG. 4.—The desert corn flea-beetle: Prepupa. Greatly enlarged. (Original.)

The full-grown larvæ just previous to changing to prepupæ are often as much as 5 mm. (three-sixteenths of an inch) long, varying from 3.5 to 5 mm. in length; the average length being about 4 mm. They are opaquely white in color, well segmented, and cylindrical in form as compared with the younger larvæ.

THE PREPUPA.

The prepupa (fig. 4) is the full-grown larva which has shrunken preparatory to pupation, and is thus reduced to about one-half its former length, though it is considerably greater in diameter. It usually lies quietly, in a curved position resembling in shape a question mark. It is segmented and of the same texture as the full-grown larva.

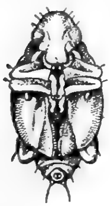

FIG. 5.—The desert corn flea-beetle: Pupa. Greatly enlarged. (Original.)

THE PUPA.

The pupa (fig. 5) very closely resembles the adult in size and appearance. It varies from 1.5 to 2 mm. in length and from 1 to 1.3 mm. in width. It is white when first formed, and has all appendages firmly compressed against the body. It is quite delicate, soft bodied, and sparsely covered with fine hairs.

LIFE HISTORY AND HABITS.

THE LIFE CYCLE.

The total length of the life cycle of this beetle in the Southwest averaged 46.3 days, with a minimum of 31 days in July and a maximum of 79 days in March, April, and May. This, of course, is subject to variation as in the case of most insects, and depends upon prevailing meteorological conditions.

The average length of the combined egg, larval, and pupal stages (Table I) of 82 specimens averaged 37.5 days for all temperatures, varying from a minimum of 24 days in June to a maximum of 65 days in March. Adding to this the average time required for the female to complete her development after issuing, before she deposits eggs, namely 9.8 days, gives the above-mentioned length of 46.3 days for the complete life cycle.

TABLE I.—*Combined length of egg, larval, and pupal stages of the desert corn flea-beetle (Chaetocnema ectypa) at Tempe, Ariz., 1915.*

Cage No.	Date adults placed in cage.	Date adults removed.	Average date of oviposition.	New adults emerged.		Combined length of stages.	Average mean temperature.
				Date.	No.		
						Days.	° *F.*
T 90	Mar. 12	Mar. 19	Mar. 16	May 13	2	58	64
T 91	...do...	...do...	...do...	May 6	2	51	64
				May 14	1	59	64
				May 20	2	65	$64\frac{3}{4}$
T 92	...do...	...do...	...do...	May 13	3	58	64
				May 20	1	65	$64\frac{3}{4}$
T. 117	Apr. 12	Apr. 19	Apr. 16	...do...	3	34	65
T 136	Apr. 26	Apr. 30	Apr. 28	June 10	2	43	71
				June 30	2	63	$74\frac{1}{3}$
T 137	...do...	...do...	...do...	June 26	2	59	$73\frac{2}{3}$
				July 3	2	66	75
T 170	May 25	May 27	May 26	June 26	2	31	$79\frac{1}{2}$
T 171	...do...	...do...	...do...	June 25	3	30	$79\frac{1}{2}$
				June 26	5	31	$79\frac{1}{2}$
				June 28	2	33	$79\frac{3}{5}$
				June 30	2	35	80
				July 3	4	38	$80\frac{3}{5}$
T 173	May 26	May 28	May 27	June 26	4	30	80
				June 30	2	34	$80\frac{1}{2}$
T 175	...do...	...do...	...do...	June 25	1	29	80
				June 26	3	30	80
T 193	June 21	June 24	June 22	July 16	4	24	$84\frac{1}{2}$
				July 17	2	25	$84\frac{2}{3}$
				July 20	2	28	$84\frac{5}{6}$
T 194	...do...	...do...	...do...	..do...	2	28	$84\frac{5}{6}$
				July 21	5	29	$84\frac{5}{6}$
				July 23	2	31	85
T 358	July 21	July 24	July 22	Aug. 23	2	32	86
				Aug. 24	6	33	86
				Aug. 25	3	34	86
T 359	...do...	...do...	...do...	..do...	3	34	86
				Aug. 26	1	35	86
Total and average	....	....	....	....	82	37.50	....

THE EGG.

The eggs are deposited at or near the surface of the ground, either on the stem of the host plant just below the surface of the ground, and within the soil, or, as was found by Mr. Wilson, on the old shell of the seed from which the plant germinated. They are usually deposited singly, but six or more may be placed at one location and at the same time. It was very difficult to make observations upon the natural place of oviposition under normal conditions because of the minuteness of the eggs and the consequent inability to see them unless the ground in which they were placed was very dark in color. In confinement beetles deposited eggs quite readily through cheesecloth upon any object which might be underneath, providing the surface of the object was kept moist. This fact was made use of in securing eggs, and cages (Pl. I, figs. 1, 2) were constructed with cheesecloth bottoms, having moist, dark-colored blotting paper beneath the cloth. The eggs, being deposited on the dark blotting paper, were easily counted and transferred to cages for records on the period of incubation.

FIG. 1.—LABORATORY CAGES USED IN LIFE-HISTORY WORK ON THE DESERT CORN FLEA-BEETLE. (ORIGINAL.)

FIG. 2.—FIELD CAGES USED IN LIFE-HISTORY WORK ON THE DESERT CORN FLEA-BEETLE. (ORIGINAL.)

FIG. 3.—JOHNSON GRASS ALONG A NEGLECTED FENCE ROW AND DITCH BANK. A DEPLORABLE CONDITION FAVORING INSECT DEVELOPMENT AND AFFORDING A PLACE FOR INSECTS TO HIBERNATE. (ORIGINAL.)

The incubation period (Table II) varied from 3 days in the month of July and August to 15 days during March and April. The average time required for 314 eggs was 5.8 days. The egg stage was secured by placing freshly laid eggs within newly made plaster of Paris cages, the eggs being placed directly upon the plaster, which had been previously darkened with waterproof India ink. This plaster not only kept the eggs sufficiently moist, but also kept down any fungous growth until the eggs could have time to hatch. Just previous to hatching the eggs darken slightly, taking on a yellowish tinge, and the larvæ escape by bursting one side of the eggshell.

TABLE II.—*Length of egg stage of the desert corn flea-beetle (Chaetocnema ectypa) at Tempe, Ariz., 1913, 1914, 1915.*

Cage No.	Date laid.	Number.	Date hatched.	Number.	Length of incubation period.	Average mean temperature.
					Days.	°*F.*
	1913.		Aug. 30	1	3	87
B[1]	Aug. 27	23	Aug. 31	8	4	85
			Sept. 1	14	5	85
C[1]	Aug. 28	24	..do....	5	4	85
			Sept. 2	19	5	84.3
D[1]	Aug. 29	62	..do....	12	4	81
			Sept. 3	40	5	81
E[1]	Aug. 30	75	Sept. 4	35	5	81
H[1]	Sept. 7	36	Sept. 11	36	4	87
L[1]	Sept. 19	5	Sept. 22	5	3	83
M[1]	Sept. 29	6	Oct. 6	5	7	71
	1914.					
2	Feb. 27	20	Mar. 12	20	13	61
			Mar. 28	17	10	64
3	Mar. 18	30	Mar. 29	6	11	63.5
			Apr. 1	3	14	62.6
4	Mar. 20	15	Apr. 3	1	14	61
			Apr. 4	7	15	61
	1915.					
T 141	May 22	25	May 27	25	5	74.6
T 163	June 12	25	June 17	25	5	80
T 239[2]	July 13	22	July 16	6	3	86
			July 17	16	4	86
T 360[2]	July 22	23	July 25	8	3	85
Totals and average	....	391	....	314	5.8	....

[1] R. N. Wilson's records. [2] L. J. Hogg's records

THE LARVA.

DURATION OF LARVAL PERIOD.

It was quite easy to secure the approximate length of the larval stage of many specimens, but owing to the feeding habits, a great deal of difficulty was experienced in securing the exact length of this stage. Various types of cages were first tried, all of them embodying the feature that the larvæ must be beneath the surface of the ground in order to insure their reaching maturity. In the past two years, however, the experiment was modified by placing the newly hatched larvæ upon small tender sections of corn root, within the cavity of plaster of Paris cages, consisting of 2 or 3 ounce salve boxes filled with newly mixed plaster in which a cavity was bored before the plaster had set. The first season that these cages were used a great many larvæ were reared partially but died before reaching maturity. Finally efforts in this direction were rewarded and six larvæ were carried successfully through from egg to pupa (Table III) during the month of June at a mean temperature of 84° F., and during this time the length of the larval stage averaged from 22 to 25 days.

TABLE III.—*Length of larval stage of the desert corn flea-beetle* (*Chaetocnema ectypa*) *at Tempe, Ariz., 1915.*

Date egg hatched.	Date of pupation.	Length of larval stage.	Average mean temperature.
		Days.	°*F.*
June 17	July 9	22	84
Do	...do	22	84
Do	...do	22	84
Do	July 10	23	84
Do	July 12	25	84
Do	...do	25	84

However, since little difficulty was experienced in securing the respective lengths of the egg and pupal stages, and then the sum of the lengths of the egg, larval, and pupal stages, it was possible from these data to obtain the length of the larval stage by subtracting the sum of the egg and pupal stages from the sum of the three stages. Thus we had the approximate length of the larval stage during practically every month in which these beetles were developing. It may be seen by consulting Tables I and III that this approximate length of the larval stage, under periods of the same temperatures, compares favorably with the exact length of the stage as noted in the case of the six larvæ mentioned. By the latter method the larval stage is found to vary from 20 days in the warm summer months to 47 days during the cooler months of the season, an average length for the larval stage of about 32 days for all temperatures.

FEEDING HABITS OF THE LARVA.

Quite soon after hatching the young larva begins eating its way into the tender succulent roots of the host plant. It thus constructs a tunnel for itself as it feeds, and soon disappears from sight. Usually the boring of the larva occurs in the cortex. On the roots of corn (fig. 6) the tunnel will often appear to be formed between the cortex and the stele or central cylinder. The reason for this attack on the cortex first is doubtless because it is more tender than the rest of the root. If the feeding be of prolonged duration the entire root may be tunneled. Many of the roots are entirely hollowed out by these "feeding mines," while in others the feeding may produce a groove along one side of the root, the larva finally entering the root and the tunnel being continued within the same. Often where two tunnels pass, the root is entirely cut off, and as is the case with small fibrous roots, they are often entirely consumed. This feeding habit frequently makes it quite difficult to locate any larvæ except those that were completely matured, and hence they were usually found in the soil at some distance from the root. The larvæ consume a considerable amount of food. A single larva confined in a plaster of Paris cage entirely consumed a section of root one-fourth of an inch long and one-sixteenth of an inch in diameter.

LARVAL FOOD PLANTS.

The food plants of the larvæ do not differ materially from those of the adults. The amount of damage done to these various food plants does, however, differ considerably as between the larva and adult. Alfalfa is rarely, if ever, injured by the adults, while the larvæ do a considerable amount of damage to alfalfa roots, especially in alfalfa fields which have been seeded to a grain crop such as barley, oats, or wheat during the winter. It is upon corn, however, that the larvæ do their greatest damage. This is, of course, due to the fact that the feeding of the adults is concentrated upon newly growing corn each spring, and egg deposition consequently becomes much heavier, the resulting damage being accordingly great.

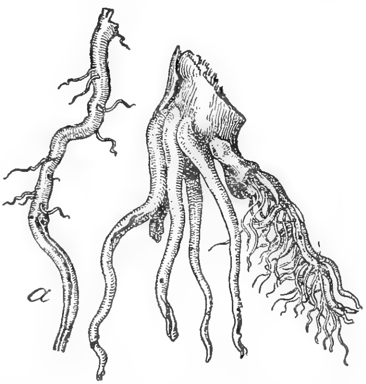

FIG. 6.—Section of corn root showing injury by larvæ of the desert corn flea-beetle. About one-half natural size. (Original.)

THE PREPUPA AND PUPA.

When the larva becomes full grown it constructs an oblong earthen cell in which to change, (1) to a transitional or prepupal stage, and (2) after a further period of a few days, to the true pupal stage. These pupal cells average about three-thirty-seconds of an inch in length, the inner walls being quite smooth. In constructing its cells the larva, owing to the fact that it is longer than its cell, must be doubled back upon itself, thus working in very close quarters. As soon as the cell is completed the larva changes to a prepupa. In this stage the body length shrinks while the diameter greatly increases, and the larva changes to a plump, rotund object shaped like a question mark. This stage, as shown by Table IV, varies in length from 2 to 8 days, the average being 3.4 days for 10 specimens. This was ascertained by taking larvæ that had already constructed their pupal cells, placing them in a vial, and allowing them to go through these various changes in plain sight.

TABLE IV.—*Duration of prepupal and pupal stages of the desert corn flea-beetle (Chaetocnema ectypa) at Tempe, Ariz., 1915.*

Pupa No.	Date prepupa formed	Date of pupation.	Length of prepupal stage.	Date adult issued.	Length of pupal stage.	Average mean temperature.
			Days.		*Days.*	*° F.*
1	Apr. 30	May 6	6	May 13	7	70
2	do	do	6	do	7	70
3	May 8	May 10	2	May 14	4	76
4	May 10	May 12	2	May 17	5	75
5	do	do	2	do	5	75
6	do	do	2	do	5	75
7	Apr. 27	Apr. 29	2	May 11	12	68
8	do	May 5	8	May 13	8	70
9		May 7		do	6	70
10		do		do	6	70
11		May 8		May 14	6	73
12		do		do	6	73
13		do		do	6	73
14		May 10		do	4	76
15		May 10(5)		May 15(5)	5	75
16		May 11		May 17	6	75
17		do		do	6	75
18	July 15	July 17	2	July 20	3	86
19	do	do	2	do	3	86
Average of 23 pupæ			3⅖		5⅔	

The duration of the pupal stage, which was determined in the same way, was found to vary from 3 to 12 days, with an average of 5⅔ days (Table IV). In a dry soil the larvæ pupate at as great a depth as 4 inches below the surface, while in an extremely moist soil the pupal cell is often formed within one-fourth to one-half inch of the top of the ground, and in one rare instance it was found at the surface of the ground just beneath some decaying vegetable matter. It can thus be readily understood that a pupa near the surface of the ground would receive more heat from the sun's rays, and consequently would develop more rapidly than one at a greater depth. This fact doubtless explains some of the variations in the combined lengths of the egg, larval, and pupal stages in some cages, the records of which appear in Table I. For instance, in cage T–136 the combined lengths of stages are shown to vary from 43 to 63 days, and in cage T–117, with a mean temperature 5 degrees lower, adults were secured in 34 days It is obvious that this presents a vulnerable point for attack in the life of this pest, for if corn is well irrigated the pupæ will be formed near the surface of the ground, and then if each irrigation is followed by a careful, close but shallow cultivation, a goodly percentage of the pupæ are exposed to the sun and the drying effects of the air, and hence killed.

THE ADULT.

The change from pupa to adult takes place rather quickly, but often a day or two passes before the adult entirely assumes the characteristic shining black. When the adults first emerge from the pupal state they are almost white, but after a short time gradually become darker, beginning with the legs, then the elytra, and finally the whole body is enveloped.

The adults are very soon able to jump nimbly and it is this habit which has given this group their name of "flea-beetles." They are quite easily alarmed, leap quickly from a plant, and, falling to the ground, often feign death in order to escape their enemies.

To the ordinary observer the males and females are very much alike, the difference being largely one of size, the male averaging slightly smaller than the female. A gravid female can be distinguished by the size of her abdomen, but large males are often larger than small females, so that the distinction is not very reliable.

ADULT DEVELOPMENT.

After the adults emerge several days must elapse before their sexual development is completed. Numerous records on this point were made by the writer as well as by J. H. Newton, assistant in the bureau at Tempe, and it was found that copulation usually takes place from 4 to 6 days after emergence and oviposition from 4 to 5 days thereafter. Table V shows the length of the period elapsing from issuance to oviposition as observed in five females. This varied from 7 to 14 days, the average being 9.8 days.

TABLE V.—*Length of life of the desert corn flea-beetle* (*Chaetocnema ectypa*) *at Tempe, Ariz., 1915.*

Date adult issued.	Date oviposition began.	Age at beginning of oviposition.	Adult died.	Length of life.
		Days.		*Days.*
On or before Apr. 25	Apr. 29	....	June 1	38+
On or before Apr. 20	Apr. 28	....	May 31	41+
May 7 (3)	May 22	14	May 27	20
May 17	May 26	9	June 15	29
Do	May 29	12	...do....	29
July 16	July 23	7	July 31	15
Do	July 25	9	...do....	15
On or before Apr. 28	May 7	....	July 20	83
Average	....	9.8	....	33.6

NUMBER OF EGGS DEPOSITED BY ONE FEMALE.

The females usually lay their eggs in stages, there being from one to two, and sometimes three, different egg-laying stages, often extending over half a month. As shown in Table VI, a female may deposit all her eggs in a single day, or in two or more successive days, or she may deposit only a part of them and then rest from four to five days, after which another large number may be deposited; then, after another period of three or more days, a third deposition of eggs may occur.

TABLE VI.—*Egg-laying record of 13 females of the desert corn flea-beetle (Chaetocnema ectypa) at Tempe, Ariz., 1915, by L. J. Hogg.*

Female No. 8	18	13	0	1	1	0	10	0	0	16	....	....	....	....	....	....	....
Female No. 7	11	0	0	13	0	0	0	0	0	1	0	0	0	0	0	0	11
Female No. 10	1	1	6	0	0	0	0	31	0	1	....	....	....	....	....	....	....
Female No. 5	22	0	0	0	0	1	....	....	....	....	....	....	....	....	....	....	....
Female No. 12	16	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Female No. 14	3	0	2	12	4	0	0	10	7	13	0	1	1	0	4	0	28
Female No. 15	5	0	0	6	12	0	36	0	0	0	0	15	0	5	0	22	....
Female No. 6	1	3	1	4	28	0	21	11	....	....	....	....	....	....	....	....	....
Female No. 16	5	0	0	8	7	....	....	....	....	....	....	....	....	....	....	....	....
Female No. 1	8	0	0	1	0	5	1	0	12	0	0	0	0	0	0	14	4
Female No. 4	1	0	12	0	14	0	3	0	6	0	0	0	19	....	....	....	....
Female No. 9	23	0	0	0	0	0	0	10	0	30	0	0	15	33	0	0	15
Female No. 11	6	0	4	0	13	0	0	3	6	....	....	....	....	....	....	....	....

NOTE.—This table shows the record of a female from the day she started oviposition until the day she finally completed the same and does not show her length of life, either before or after oviposition.

The females are quite prolific, often laying from a dozen to over 100 eggs each. During June of 1915 the writer recorded four females which laid, respectively, 19, 57, 20, and 29 eggs, while three females, all confined in the same cage, laid a total of 145 eggs, averaging 48 eggs each in a period of 12 days. Mr. L. J. Hogg during August of the same year made oviposition records upon 16 females which he had under observation, the number of eggs for each female being as follows: 23, 40, 85, 101, 69, 20, 45, 11, 55, 17, 126, 36, 39, 25, 23, 14.

LENGTH OF LIFE.

In cages the adults usually died within a week or 10 days after oviposition was completed, but in some cases the length of life of the adult beetles was often prolonged. As shown in Table V, it varied from 15 to 83 days, the average for these eight specimens being 33.6 days.

It is suspected that in the field, under natural conditions, where they are better able to protect themselves from the sun and from the moisture which was nearly always more or less present in small vial cages, the length of life might be even longer than that recorded in this table.

METHODS OF FEEDING.

The adult beetles usually feed during the cooler parts of the day in the warm summer months and during the warmer parts of the day in the cooler spring and fall months. During the summer they protect themselves by getting down within the infoliations of the plants, where they may secure tender succulent food and at the same time be protected from the heat. In feeding a beetle will stand crosswise on a corn leaf and with its strong mandibles eat out a portion of the epidermis between two parallel veins, continuing in a straight line, often 1 or 2 inches in length. They rarely eat a hole entirely through a leaf. In cases where extremely heavy feeding occurs and where the infestation is great, the green portion is entirely eaten out, and the leaf has a burned or scarred appearance.

SEASONAL HISTORY.

NUMBER OF GENERATIONS ANNUALLY.

The desert corn flea-beetle usually appears about the middle of February each spring. The time at which the beetles may first be found actively feeding in the field will, of course, depend upon the season. In the year 1912 Mr. R. N. Wilson first took these beetles on February 14, sweeping a few specimens from a barley field. In 1913 the same observer took a few feeding beetles on January 13. The month of January of that year, however, was quite warm and advanced over the ordinary year. In the year 1914 Mr. D. J. Caffrey took adults for the first time on February 20. These were feeding in a green wheat field. In the spring of 1915 Mr. F. H. Gates first swept adults in an alfalfa field on February 9. They did not, however, become abundant until February 23, when both the author and Mr. Gates secured an abundance of this species.

It is only a few weeks after emergence that these hibernating adults begin depositing eggs. The earliest date that eggs have been secured in cages was March 12, 1915, at which time the writer secured eggs in considerable numbers. There are from three to four generations each year in the Salt River Valley. The first generation, starting with eggs deposited in early March, appears about the first of June. Another generation quickly follows, adults coming forth about the middle of July, a third generation is completed by the first to the middle of September, and in occasional years there is a partial fourth generation.

The fact, however, that the length of each individual life cycle is determined quite largely by the proximity of both larvæ and pupæ to the surface of the ground is responsible for the general intermingling of the various generations, so that eggs may be secured throughout the breeding season. Eggs have been secured in cages throughout the year, beginning with the first of March and continuing to the middle of October. Mr. Wilson has secured eggs in cages during the months of May, June, July, August, September, and October, while the writer has secured eggs during March, April, May, and June, and these records were followed up by those of Messrs. Hogg and Newton, who obtained eggs during July, August, and September of the same year. Of course, eggs deposited the first of October would, ordinarily, not reach maturity, while those deposited in the middle of September in some seasons develop a partial fourth generation. From October 13, 1914, to March 9, 1915, the writer maintained in a laboratory cage a large number of Chaetocnema adults which had been collected from the field, but did not secure a single egg during this time.

HIBERNATION.

From the foregoing remarks on the generations it is at once seen that these adults usually are found hibernating during the latter part of November, in December, and in January. They enter hibernation gradually during November, and one is rarely able to find adults throughout December and January, although on an occasional warm day specimens might be secured during any winter month. On Nov. 7, 1912, at Tempe, Ariz., Mr. R. N. Wilson made the following note:

Only a few Chaetocnema could be found on corn on the Godfrey field to-day.

Then on November 23, 1912, he made the following observation:

The corn on the Godfrey field has been cut since the field was last visited. No specimens were found.

On December 14, 1914, also at Tempe, the writer observed adults in hibernation and made the following record:

A few Chaetocnema adults were found to-day in protected places, as back of sheath leaves, in an old cornfield, and at the base of wild barley plants that thickly covered the ground. The species is apparently very quiet at this time and can be said to be hibernating. The past week has been rather cold and several mornings the temperature fell to considerably below freezing. One or two specimens were noted, however, that appeared quite active.

The hibernating adults may be found beneath anything that will give them protection, such as rubbish and grass clumps in waste places. A favorite place for adults to winter is along ditch banks thickly grown up with Bermuda and Johnson grass. These places seem to be ideal because, late in the winter or early in the spring, they become overgrown with wild barley, and this plant gives the beetles succulent food the first warm days in the spring. Waste salt places which are not too wet and are grown up with salt grass also afford ideal conditions for hibernation quarters, and the beetles have been observed on this grass quite early in the spring. Early in 1912 Mr. R. N. Wilson made the following note:

At the northeast corner of this farm there is a large patch of salt grass (*Distichlis spicata*), which forms a thick mat on the ground. Sweepings made on this grass to-day revealed many Chaetocnema. This is likely one of their food plants, and probably furnishes an ideal place for hibernation.

NATURAL ENEMIES.

Judging from our present knowledge of this species, it seems to be fairly free from the attacks of enemies of any kind. While it is quite possible that it is occasionally picked up by birds, yet no definite observations have ever been made upon this, and the Bureau of Biological Survey has no records bearing upon this species, though related species have been found to be taken as food by certain birds.

PREDACIOUS ENEMIES.

The larvæ of this beetle are without doubt fed upon by several subterranean larvæ of ground beetles which have been found to inhabit the soil in the vicinity of corn plants. The adults are preyed upon by the nymphs and adults of *Reduviolus ferus* L. Mr. Wilson first took specimens of these nymphs, which be found feeding upon Chaetocnema adults, at Tempe, Ariz., and reared them to maturity, and then found that both adults and nymphs were feeding upon the flea-beetles. It is quite likely that other reduviids also attack this species.

At Holtville, Cal., the writer found a great many beetles with their bodies almost covered by a species of mite. Upon being sent to Washington these mites were determined by Mr. Nathan Banks as *Pediculoides* sp. They have since been found quite frequently upon adult flea-beetles.

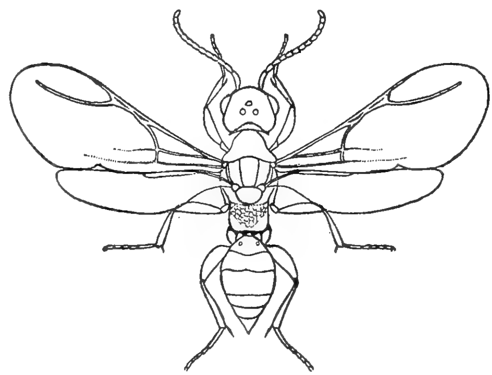

FIG. 7.—*Neurepyris* sp., a parasite of the desert corn flea-beetle. Greatly enlarged. (Original.)

PARASITIC ENEMIES.

During his observations in 1915,[1] the writer discovered that a small parasitic wasp, *Neurepyris* sp.[2] (fig. 7), was preying upon the arvæ and prepupæ of this flea-beetle. Six specimens taken in the soil, already within the pupal cases, were each found to have very small, insignificant external larvæ feeding upon them, the larvæ being attached to the ventral side just back of the hind pair of legs. These were carefully placed in small vials, and subsequently several of the parasites died, while one specimen pupated and finally changed to an adult, the hymenopterous larvæ in the meantime having completely consumed the beetle larvæ.

The adult of this parasite is very small, black, with yellow legs, and its pupal case, which is about the size of a Chaetocnema pupa, is constructed in the soil of a brown, densely woven material. The larval stage of this parasite was found to be about 8 days and the pupal stage 24 days. This was during the month of May, with the mean temperature about 76° F.

[1] At Tempe, Ariz.

[2] Determined by Mr. S. A. Rohwer.

REMEDIAL AND PREVENTIVE MEASURES.

The control of this insect over a wide area can be accomplished only by cultural methods, the eradication of its hibernation quarters, and the destruction of some of its favorite native and adopted grass and weed food plants. In smaller areas, consisting of only a few acres, a certain degree of success can be expected from the use of arsenate of lead as a spray. Several experiments were tried, using different kinds of repellents, but without any great amount of success.

The greatest damage is done to the plant just as it is coming through the ground, because at this time it is more tender and attractive to the beetles and also is less resistant to insect attack. If, therefore, the growth of the plant is stimulated by good cultivation, fertilizers, or any other stimulative measures, as has been recommended by Mr. Wilson in his notes upon this species, then the plant will have an excellent chance in spite of the flea-beetles. If the numbers of the beetles are also lessened by the cleaning up of hibernation quarters and the eradication of breeding places, the plants will have a still greater chance of reaching maturity, and finally, if the plants are sprayed by arsenate of lead, as will be shown later, the damage will be almost negligible.

REPELLENTS.

While located on a ranch south of Holtville, Cal., in April, 1910, the writer undertook to determine the value of several volatile oils and also of naphthalene balls, as repellents for this beetle. The oils used were those of eucalyptus, citronella, and pennyroyal. A small piece of cotton was placed in the ground, even with the surface of each hill of corn treated, and was moistened with the oil each morning for five days, while the naphthalene balls were utilized by placing a single ball beside a hill of corn. Two rows were treated with each of the four remedies used and every third row was left untreated as a check row, the idea being that if the corn could be protected for a few days it would reach a stage of growth in which it would be able to withstand an attack from the flea-beetles. The results of this experiment may be summarized as follows: The naphthalene balls and the oil of eucalyptus were found to act in no way as repellents of this beetle. The rows treated with the oil of citronella were damaged the least by the flea-beetles, while the rows treated with the oil of pennyroyal were damaged only slightly. However, since the cost of these oils and the time taken in application were found to be prohibitive from an economical standpoint, and since the results were not conclusive, the use of these repellents can not be recommended.

POISONS.

Speaking in regard to the control of this flea-beetle on Sudan grass, Dr. A. W. Morrill [1] states:

> Experiments with applications of Bordeaux mixture and arsenate of lead to the infested grass failed to give satisfactory results.

Later than this, after additional experiments, he remarks: [2]

> Spraying the plants with arsenate of lead, using one ounce of arsenate of lead powder to one gallon of water, is the only remedial measure which can be recommended at the present time.

Prof. Freeman,[3] in his bulletin previously mentioned, speaking of the injury from this little flea-beetle, says:

> The plants were all sprayed twice with lead arsenate, but very little benefit could be ascribed to this treatment.

In correspondence with Prof. Freeman, the writer was informed that he used arsenate of lead without soap in the solution, and he says that the spray collected in drops upon the corn foliage, and attributes the failure of the arsenate of lead to this fact.

The writer first used 1 pound of powdered arsenate of lead to 50 gallons of water, but without any success whatever, the beetles being fully as numerous on rows treated as on those not treated. It was easily seen that this was due to the fact that the solution of arsenate of lead did not stick to the corn leaves. Later an experiment was tried, using powdered arsenate of lead, 2 pounds to 50 gallons of water, mixed in a strong soap solution which caused the diluted poison to stick well to the surface of the leaf. This seemed to act both as a repellent and as a poison to the beetles, and the treated rows were in no way injured by the attack of these flea-beetles. While additional experiments must be carried on with regard to the use of this poison, from the writer's past observations it can be used in this manner upon small areas of corn, applied by means of a small spray pump, with very satisfactory and practical results.

CULTURAL METHODS.

As has been pointed out in the discussion of the pupal stage of this flea-beetle, if the soil be kept fairly moist the pupæ will form near the surface of the ground and within 2 or 3 inches of the corn plant. Now, if precautions are taken to follow each irrigation by a very shallow cultivation close to the plant and shallow enough to insure no tearing of the root surface, a great many pupæ will be

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[1] Morrill, A. W. Report of the entomologist of the Arizona Commission of Agriculture and Horticulture. Ariz. Com. Agr. Hort., 6th Ann. Rpt., p. 33, 1914.

[2] Morrill, A. W. The Corn Flea Beetle. *In* Ariz. Agr. Exp. Sta. Bul. 75, p. 468. May, 1915.

[3] Freeman, G. F. Papago sweet corn, a new variety. Ariz. Exp. Sta. Bul. 75, p. 462. May, 1915.

destroyed and damage to future crops will be greatly lessened. Such cultivation will not only assist in reducing the number of beetles maturing, but it will also aerate the ground and place it in a thrifty condition, producing strong healthy plants that will be able better to withstand insect attacks.

This point should not be passed without mention of the fact that stable and barnyard or corral manure, which, in the Salt River Valley, is ordinarily dumped in waste places, on ditch banks, or absolutely destroyed, as it were, should be utilized in building up the soil and making it still more productive than it is at the present time. Manure is ordinarily not used in the warm southwestern country because it is claimed that it causes burning of the plants and contributes to the dispersion of weed seeds. If manure is thoroughly rotted and properly applied it will not burn the plants, and if rotation of crops is practiced, there will be a minimum of complaint in regard to the dissemination of weed seeds.

Mr. E. W. Hudson, who has been in charge of the Bureau of Plant Industry Experimental Farm at Sacaton, Ariz., and who is well acquainted with farming conditions in the Southwest, believes that all manure should be utilized, and if it is to be plowed under it should be applied in the fall, turned under, and given a chance to decay during the cool part of the year. If used at other times of the year, he believes that it should be applied by the aid of a manure spreader as a light top-dressing. The writer is thoroughly in accord with this latter method, for in addition to putting the nourishment just where it is needed by spreading the manure over the ground where it soon dries, the breeding of flies is also avoided. If all manure and refuse were handled in this manner, there would be a considerable reduction in the fly population of these regions.

If land well treated with stable manure is afterwards planted to corn, the plants will be enabled to make a good start and continue in a thrifty condition in spite of flea-beetle attack.

ERADICATION OF JOHNSON GRASS AND OTHER TROUBLESOME GRASSES.

Since it has been shown that this flea-beetle lives quite largely upon Johnson grass (*Sorghum halepense*) and salt grass (*Distichlis spicata*), it is obvious that the fewer of these grasses found growing in alfalfa fields or cultivated fields of any kind and also along roadsides and ditch banks, the fewer the number of beetles to attack the cultivated crops. While Johnson grass may be a difficult and troublesome grass to control, yet there is no excuse for allowing it to become an almost inaccessible thicket, 15 to 20 feet wide, along roadsides, fence rows, and ditch banks, as is sometimes found to be the case in Arizona. Each farmer should consider it a part of his duty to the community in which he lives to mow such places two or three times a year, or to pasture them with sheep, thus keeping down all weed and grass growth.

ELIMINATION OF HIBERNATION QUARTERS.

Cleaning up weeds and grasses will eliminate a great many of the hibernation quarters of this beetle, and if such methods can be carried further, to include all waste places and any place where trash may accumulate, then the hibernating beetles will not be able to protect themselves from the colder days and frosty nights of the winter months and their numbers will be reduced.

SUMMARY.

The desert corn flea-beetle is present in injurious numbers in the cultivated areas of the southwestern United States, where it takes an annual toll upon such crops as corn, milo maize, sugar cane, Sudan grass, wheat, barley, and alfalfa. Both the adults and the larvæ are concerned in injuring crops, the adults feeding upon the top of the plant and the larvæ upon the roots.

The eggs are deposited at or near the surface of the ground and hatch in about six days. The young larvæ are found within the tender roots of the food plants, while the older larvæ are found in the soil near these roots. The average length of the larval stage is found to be 32 days.

The prepupal and pupal stages are both passed within a cell in the soil near to the roots on which the larvæ fed.

The flea-beetles hibernate in the adult stage under rubbish or at the base of various grasses growing in the regions of infestation.

The total length of the life cycle of this flea-beetle is about seven weeks, there being from three to four generations each year.

The numbers of adult flea-beetles can be reduced greatly by cleaning up hibernation quarters and eradicating some of their weed food plants, such as Johnson grass, salt grass, and Bermuda grass. They can be further reduced by carefully cultivating such crops as can be cultivated just as soon as the soil becomes dry, following each irrigation. This method destroys a great many pupæ. Small pieces of corn can be sprayed successfully with arsenate of lead, using 2 pounds to 50 gallons of water, the water being made into a strong soap solution. This acts both as a repellent and as a poison to the beetles.

Injury to corn and other crops can be overcome partially if the soil is placed in the best possible cultural condition by the addition of barnyard manure or other fertilizer.

The nymphs and adults of a predacious hemipteron (*Reduviolus ferus* L.) were observed to feed upon these beetles, and a small parasitic wasp, *Neurepyris* sp. (fig. 7.), was found to prey upon the larvæ and prepupæ.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 437

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER January 16, 1917

FLAT-HEADED BORERS AFFECTING FOREST TREES IN THE UNITED STATES.

By H. E. Burke, *Specialist in Forest Entomology, Forest Insect Investigations.*

CONTENTS.

	Page.
Importance of flat-headed borers	1
Food plants	2
Character of the work	2
Life history	2
Seasonal history	2
Special habits	3
Special structural characters	3
Agreement of adult and larval classifications	4
Distinguishing characters	4
Key to genera of buprestid larvæ	5
List of genera, distribution, common habits, and host trees	6
References to important literature	8

IMPORTANCE OF FLAT-HEADED BORERS.

Flat-headed borers (buprestid larvæ) are among the most important of the borers infesting forest trees in the United States. Some mine the leaves, one burrows into the cones, a number bore into the inner bark and outer wood of the trunk, branches, and roots, while the majority excavate oval winding "wormholes" throughout the sound or decaying sapwood and heartwood.

At present the leaf-miners and the cone-burrower are not common enough to be important. The bark-borers often girdle and kill healthy trees or those injured by fire, floods, droughts, diseases, other insects, or careless lumbering, and at other times weaken trees so that they become easy victims of diseases, other insects, or unfavorable environment. Sometimes when they do not kill the tree outright their work causes dead limbs or twigs, or serious defects, checks, or gum spots to form in the wood, or swollen galls to form on the branches. The wood-borers mine the sapwood and heartwood of the trunk, top, and larger branches and thus destroy or seriously injure a large amount of the tree's most valuable product, its timber. Wormholes will cause the finest grade clear lumber to become unfit for the higher grade uses and therefore unsalable at the higher prices.

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FOOD PLANTS.

Both deciduous and coniferous trees, as well as shrubs and herbaceous plants, are attacked. Some genera attack only deciduous trees, some only conifers, while others attack both. Plants of any age may be attacked and any part of the plant from the roots to the leaves, but the principal part is the bark and wood of the main trunk.

CHARACTER OF THE WORK.

The borer work or injury consists of a flattened, oval, gradually enlarging, more or less tortuous mine or wormhole (Pl. VIII, figs. 1, 2), which, when completed, widens out into an elongate oval pupal cell. This cell connects with the outer surface by a short, oval exit hole. The mine has its surface marked by fine, transverse, crescentic lines and is usually tightly packed with arc-like layers of sawdust-like borings and pellets of woody excrement. The injury may be entirely in the bark, entirely in the wood, or, as is usually the case, in both bark and wood.

LIFE HISTORY.

All bark and wood boring flat-headed borers hatch from eggs deposited by the mother beetle singly or in a mass (Pl. IX), on the bark or tucked in some crevice in the bark or wood or under the bark at the edge of a wound. Each larva mines the inner bark or wood until it reaches maturity, when, after mining outward nearly to the surface, it retreats into its mine and forms an oval cell, in which it pupates and transforms to an adult beetle. The beetle rests awhile, then bites its way out, feeds on the bark, foliage, or pollen of some plant, usually its host, and then mates. The female, after depositing eggs to start a new generation, soon dies.

SEASONAL HISTORY.[1]

The egg is usually laid in the spring or summer and the borer hatching from it feeds and rests until the following fall, or the second fall, or even the third fall, before it reaches maturity. It then either rests over the winter in the larval stage and pupates and transforms to the adult the following spring, or it pupates and transforms to the adult in the summer or fall and rests over the winter in the adult stage in the pupal cell. Most of the bark-borers pass the winter in the larval stage and emerge soon after pupating and transforming to adults in the spring. Many of the wood-borers pupate and transform to adults in the summer or fall and pass the winter

[1] Some evidence has been obtained which indicates that certain species may pass the winter in the egg stage. Mr. A. B. Champlain collected a mass of eggs at Colorado Springs on February 12, 1914, which produced young *Chalcophora* larvæ. Certain *Agrilus* larvæ feed in the spring a short time before pupatings and transforming. Individuals of some species pass the winter in the pupal stage. No observation have been made which would indicate that the adults live over the winter after they have emerged.

in the adult stage before emerging. Feeding begins soon after emergence, and mating, egg-laying, and death soon follow, the whole being completed before the end of summer.

SPECIAL HABITS.

So far as known to the writer only two of our genera (*Agrilus* and *Eupristocerus*) cause the formation of galls (Pl. VIII, figs. 3, 6) on the host plant, and in these cases it seems to be more the special nature of the plant to produce the galls than it is the special work of the insect that causes them to be produced. Thus, the same species of insect will produce galls on some plants and not on others, or on one part of a plant and not on other parts of the same plant. A common western form, *Agrilus*, that infests the alder often produces galls in eastern Oregon, while it seldom does so in eastern California. The common *Agrilus bilineatus* Web. of the Eastern States hardly ever produces galls, but it will do so sometimes when it works on the smaller branches of the oak.

Besides the enlarged roughened galls, some species cause "splotch" mines to form in the bark of young shoots or branches.

Chrysophana placida Lec. usually works in the heartwood of dead branches, tops, fire scars, etc., but recently Mr. P. D. Sergent found it mining the cones of the knobcone pine (*Pinus attenuata*) in southern Oregon (Pl. VIII, fig. 5).

In pupating, it seems to be the most natural habit for the bark-borers to pupate in the bark, and most of them will do so if the bark is thick, but where it is thin they will go into the outer wood. The natural habit of the wood-borers is to pupate in the wood, but some will pupate in the bark.

Although the usual food of the adults is the foliage of the host plant (Pl. VIII, fig. 4), some are pollen feeders, and, as has been determined recently by Mr. F. C. Craighead, some will feed on the spores of fungi. In this instance the adult *Agrilus bilineatus* is of some benefit in destroying the spores of the destructive chestnut blight fungus. Mr. L. E. Ricksecker mentions (Entomologica Americana, 1885) having seen adult *Melanophila consputa* Lec. devouring scorched white ants (termites) on an old spruce log.

SPECIAL STRUCTURAL CHARACTERS.

The larvæ of the genus *Agrilus* (Pl. VI, fig. 2) and of the genus *Eupristocerus* (Pl. VI, fig. 1) bear on the thirteenth or last segment a pair of strong, heavily chitinized, toothed forks or forceps. These are absolutely distinct from any structure possessed by any other member of the family. *Polycesta* larvæ have a pair of sunken brownish spots on the head, one on each side of the jaws, a pair on the postero-dorsal surface of the third segment, and a pair on the antero-ventral surface of the fourth segment. The function of these spots is unknown, but possibly it may be auricular. *Thrincopyge* larvæ have a pair of brownish spots on the median subdorsal areas of the second and third segments which appear to be secondary spiracles.

AGREEMENT OF ADULT AND LARVAL CLASSIFICATIONS.

The buprestid larval classification agrees very well in the grosser features with that of the adults, except in the case of the genus *Anthaxia*. In adult classification this genus is placed between *Melanophila* and *Chrysobothris*, but its larval characters and life history indicate a much closer relation to *Dicerca* and its allies.

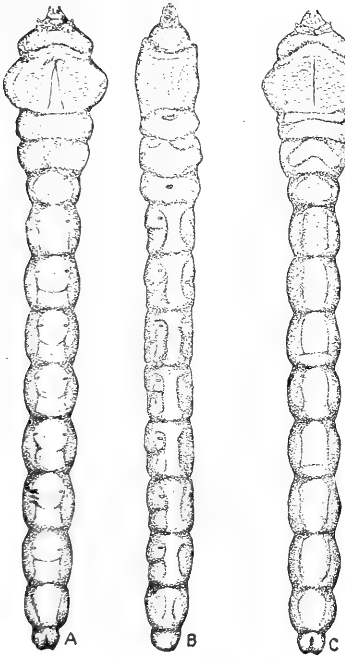
The larval characters strongly indicate that the genus *Buprestis* should be split into three genera and the genus *Melanophila* into two genera.

DISTINGUISHING CHARACTERS.

The principal distinguishing character of the buprestid larva is the occurrence of a well developed ambulatory plate (Pls. I–VI) on both the dorsal and ventral surfaces of the first segment behind the head. Both plates closely resemble one another. Similar plates occur on some of the eucnemid larvæ (Pl. VII, figs. 1, 3), but the markings are different. The buprestids have a central line, groove, or V on the dorsal plate, while the eucnemids have two lateral lines. Cerambycid larvæ (Pl. VII, fig. 2) never have the ventral plate as well developed or similar to the dorsal. Cucujid larvæ (Pl. VII, fig. 4) are very flat, but they can be distinguished from the buprestids at once because of their well developed legs.

Structurally there are two general types of buprestid larvæ: One (bark and wood borers) "flat-headed," with a long slender subcylindrical tail; the other (leaf-miners) flattened, rather oval, deeply notched, and gradually tapering to the last segment. In the first type, the first segment, taken with the second and third and sometimes the fourth, forms a broader, head-like division from the remainder, which, taken together, forms the long subcylindrical tail. In this type the first segment is much larger and broader than the others, while the thirteenth is usually much smaller. In the second type there is no distinct club head; the first and second segments are only a little narrower or a little broader than the third and fourth and the whole gradually tapers down to the thirteenth.

Both types are distinguished by the following characters: Comparatively small head more or less retracted into the first segment of a body composed of 13 fairly well defined, flattened segments; antennæ medium-sized and three-jointed; ocelli wanting; labrum rather large, arched and protruded; mandibles short, strong, usually toothed and rather spoon-shaped; maxillæ well developed; maxillary palpi two-jointed; labium well developed, arched, protruded; labial palpi minute and unsegmented, almost obsolete; first segment with a large, well-developed plate on both the ventral and the dorsal sur-



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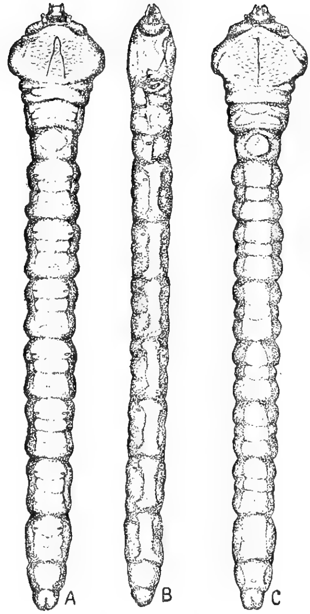

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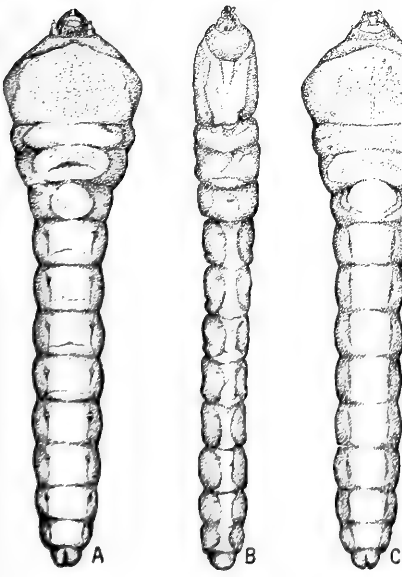

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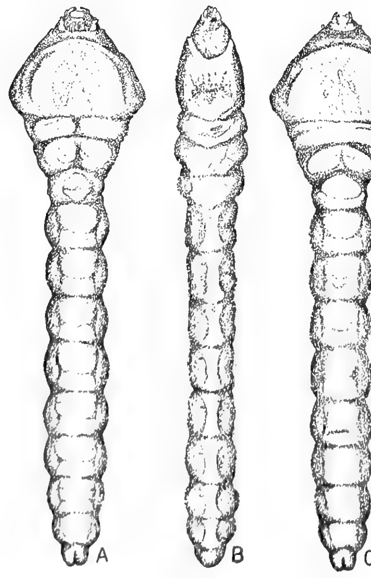

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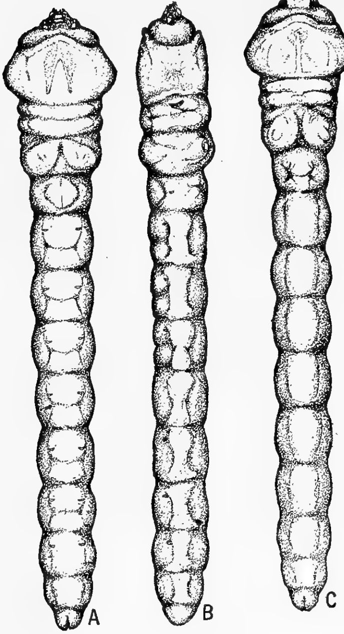
FLAT-HEADED BORERS.

FIG. 1.—*Chalcophora angulicollis:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 1\frac{1}{4}$. FIG. 2. *Chalcophorella campestris:* Larva. A, dorsal view; B, dextral view; C, ventral view. $\times 1\frac{1}{2}$. FIG. 3.—*Buprestis apricans:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 2$. FIG. 4.—*Buprestis aurulenta:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 2\frac{1}{2}$. (Drawings by Eleanor T. Armstrong.) (Original.)



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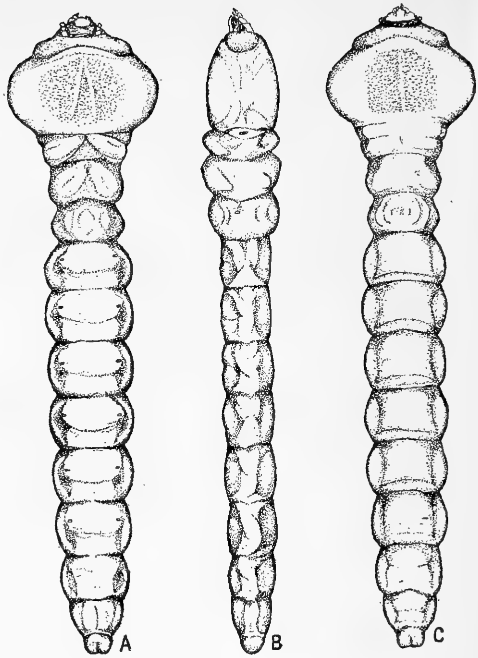

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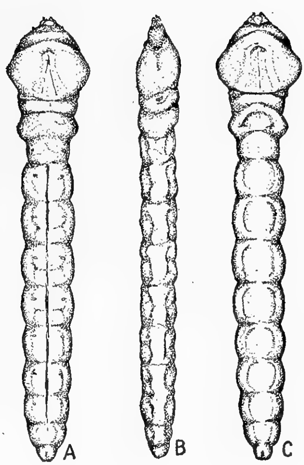

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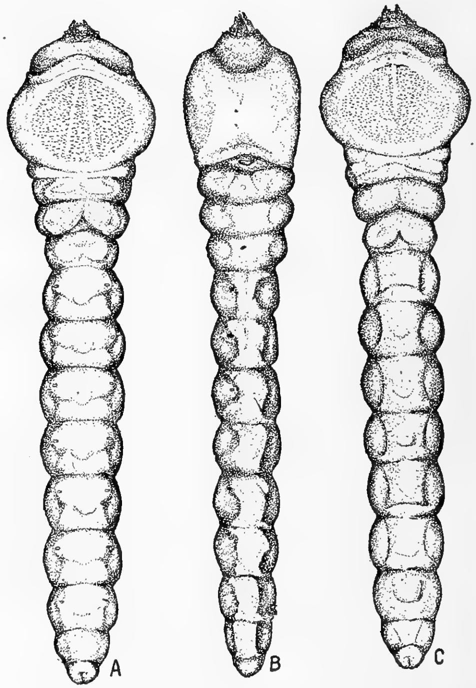

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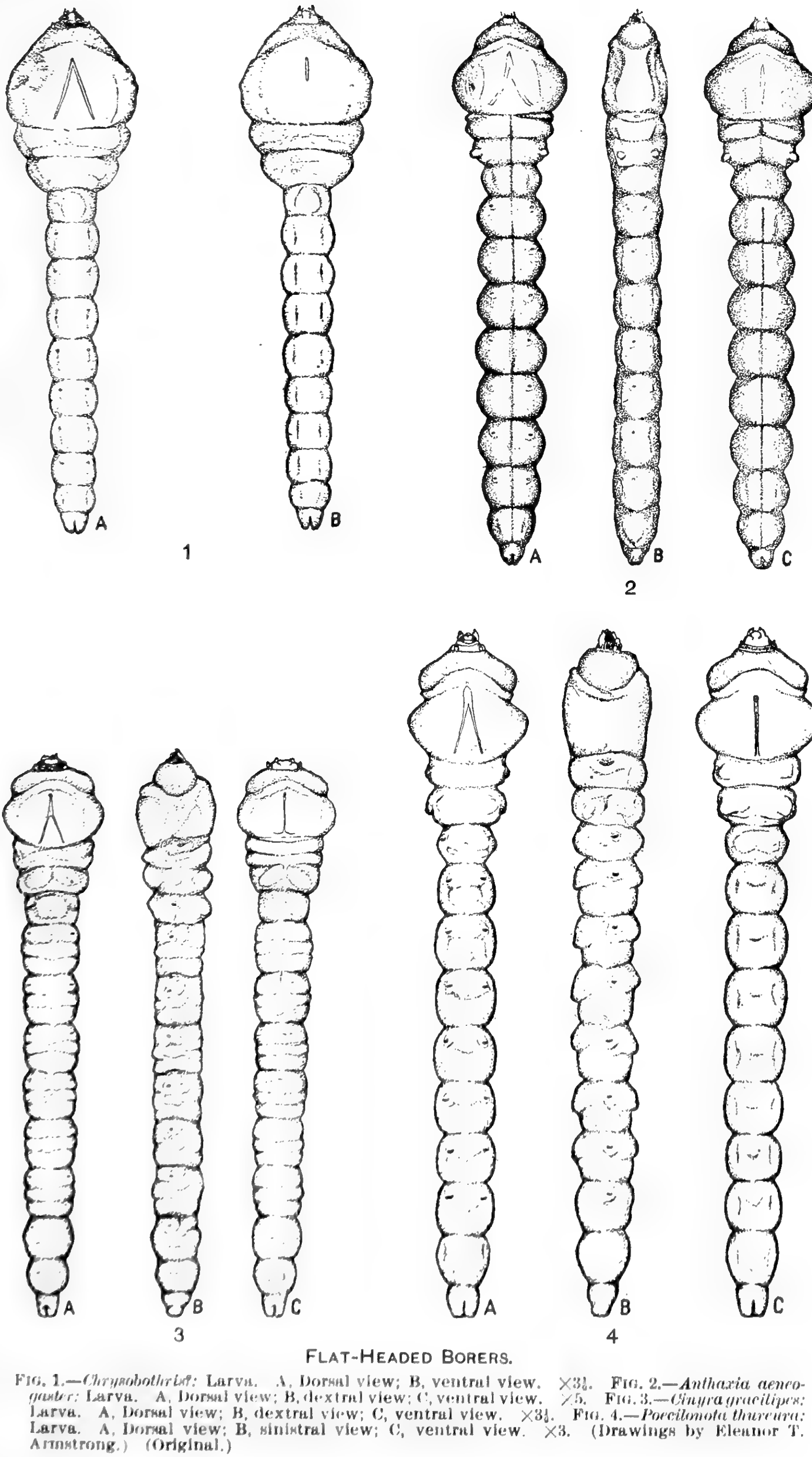
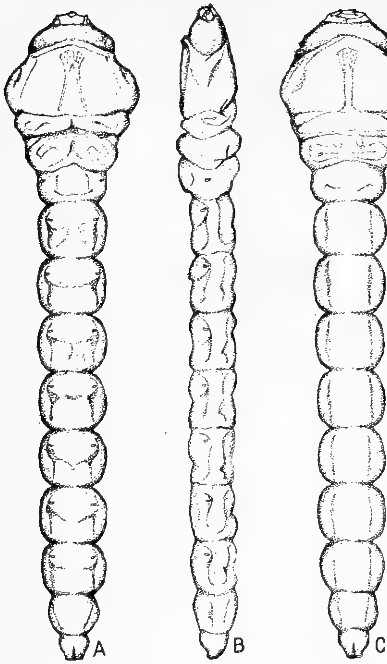
FLAT-HEADED BORERS.

FIG. 1.—*Buprestis laeviventris:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×2.
FIG. 2.—*Melanophila drummondi:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3½.
FIG 3.—*Melanophila intrusa:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3½.
FIG 4.—*Chrysobothris trinervia:* Larva. A, Dorsal view; B, dextral view; C, ventral view.



FLAT-HEADED BORERS.

FIG. 1.—*Chrysobothrid:* Larva. A, Dorsal view; B, ventral view. ×3½. FIG. 2.—*Anthaxia aeneogaster:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×5. FIG. 3.—*Cinyra gracilipes:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3½. FIG. 4.—*Poecilonota thureura:* Larva. A, Dorsal view; B, sinistral view; C, ventral view. ×3. (Drawings by Eleanor T. Armstrong.) (Original.)



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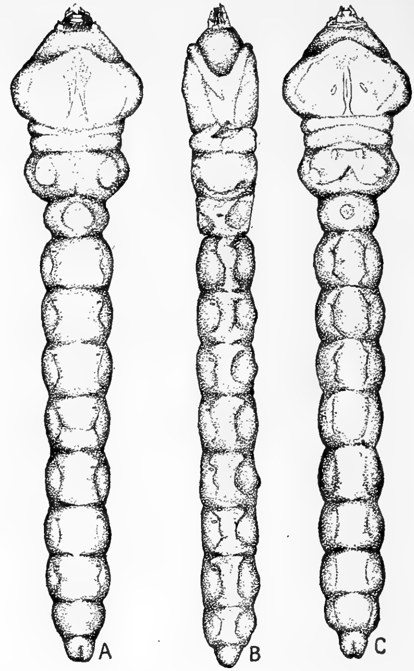

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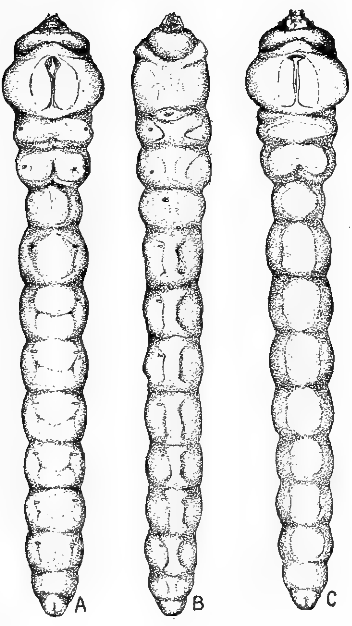

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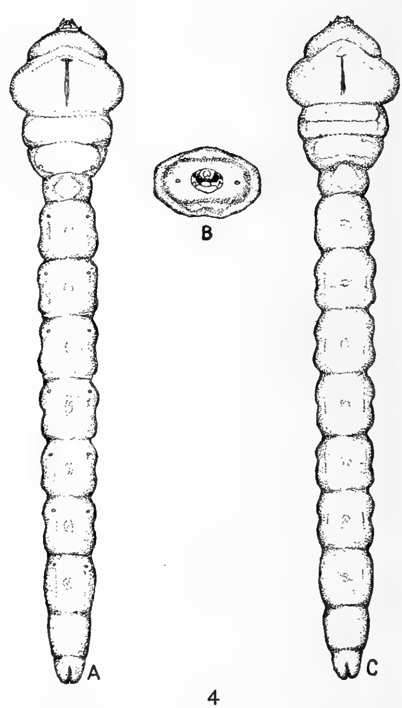

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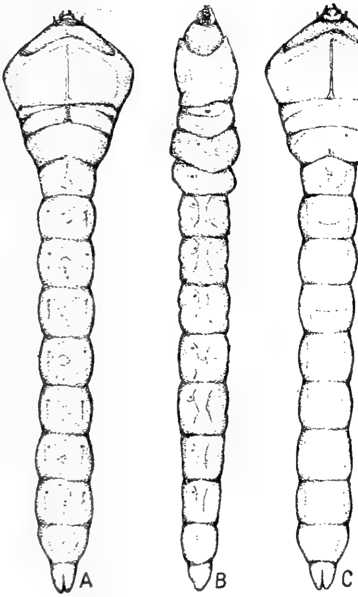
FLAT-HEADED BORERS.

FIG. 1.—*Dicerca prolongata:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 2\frac{1}{3}$.
FIG. 2.—*Trachykele lecontei:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 3$.
FIG. 3.—*Thrincopyge ambiens:* Larva. A, Dorsal view; B, dextral view; C, ventral view. $\times 2$.
FIG. 4.—*Polycesta velasco:* Larva. A, Dorsal view; B, cephalic view; C, ventral view. $\times 1\frac{1}{2}$.
(Drawings by Eleanor T. Armstrong.) (Original.)



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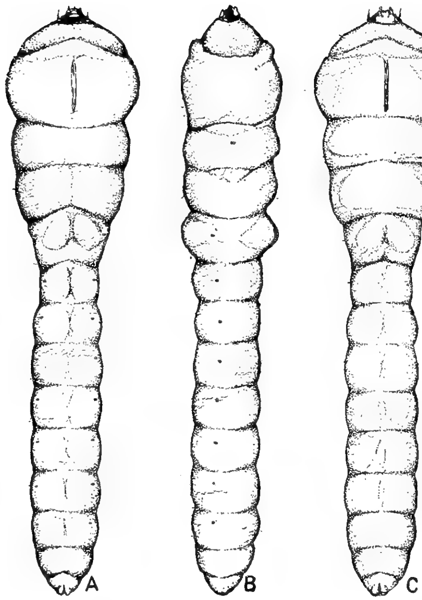

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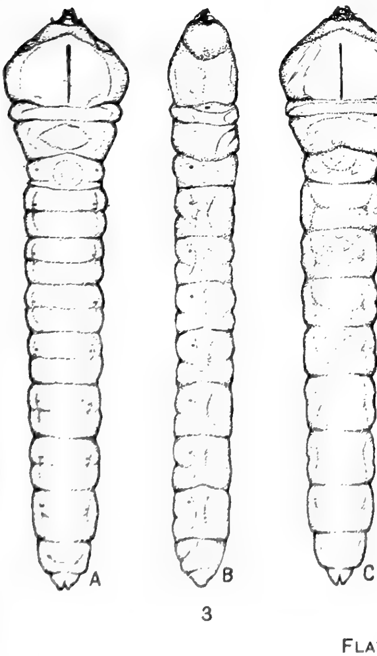

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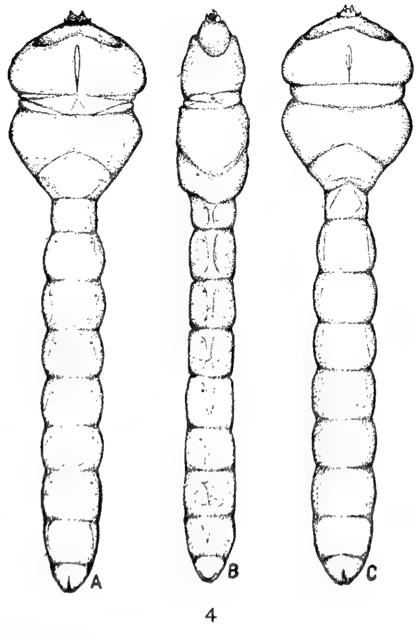
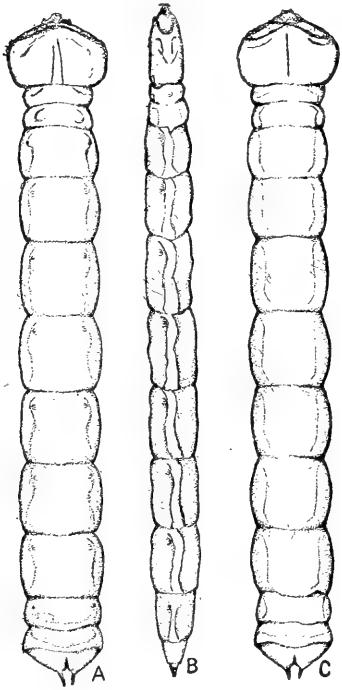


4

FLAT-HEADED BORERS.

FIG. 1.—*Chrysophana placida:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×4½.
FIG. 2.—*Acmaeodera prorsa:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×4.
FIG. 3.—*Ptosima gibbicollis:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×5.
FIG. 4.—*Tyndaris olneyae:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3½.
(Drawings by Eleanor T. Armstrong.) (Original.)



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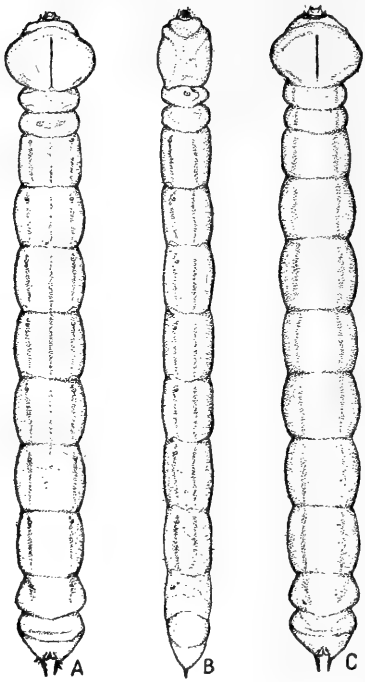

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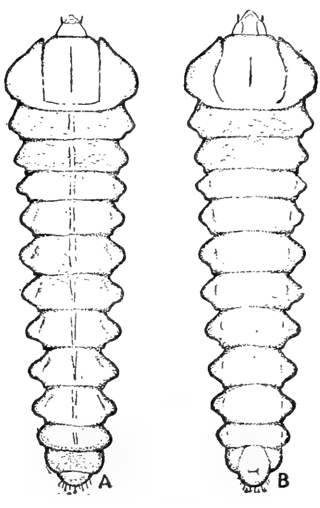

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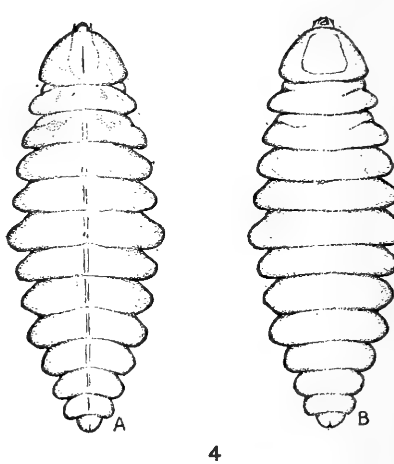
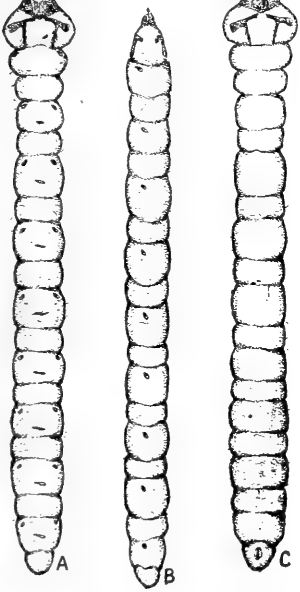


4

FLAT-HEADED BORERS.

FIG. 1.—*Eupristocerus cogitans:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3½. FIG. 2.—*Agrilus bilineatus:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×4½. FIG. 3.—*Brachys aerosa:* Larva. A, Dorsal view; B, ventral view. ×5. FIG. 4.—*Pachyscelus schwarzii:* Larva. A, Dorsal view; B, ventral view. ×10. (Drawings by Eleanor T. Armstrong.) (Original.)



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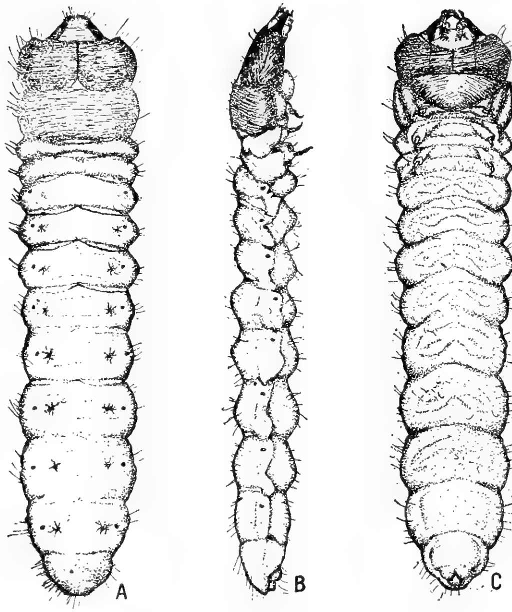

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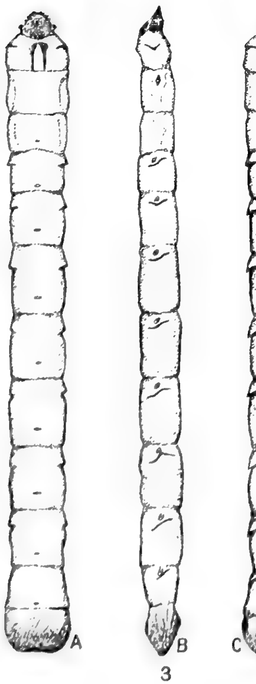

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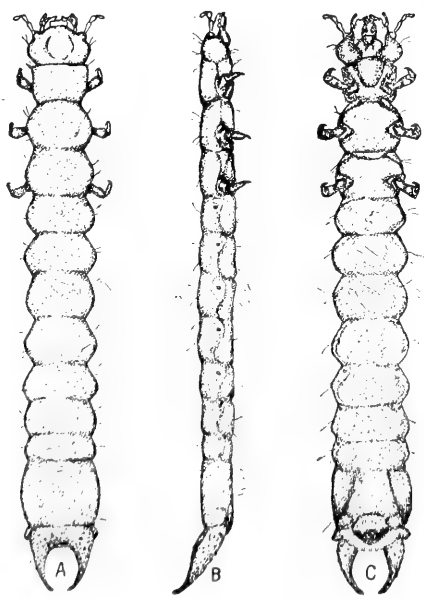


4

EUCNEMID, CERAMBYCID, AND CUCUJID LARVÆ.

FIG. 1.—*Melasis rufipennis:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3. This is a cross borer (eucnemid) often mistaken for a flat-headed borer (buprestid). FIG. 2.—*Rhagium lineatum:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3. This is a round-headed borer (cerambycid) often mistaken for a flat-headed borer (buprestid). FIG. 3.—*Dromaeolus nitens:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3. This is a cross borer (eucnemid) often mistaken for a flat-headed borer (buprestid). FIG. 4.—*Cucujus puniceus:* Larva. A, Dorsal view; B, dextral view; C, ventral view. ×3. A very flat larva found under bark but not a flat-headed borer. (Drawings by Eleanor T. Armstrong.) (Original.)

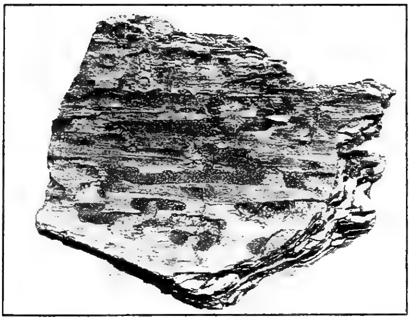


FIG. 1. Bark from dying yellow pine (*Pinus ponderosa*) mined by larvæ of *Melanophila drummondi*. ×¼. (Photograph by H. E. Burke.) (Original.)

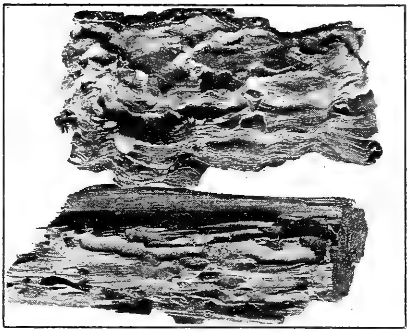


FIG. 2.—Wood from scar on living red fir (*Abies magnifica*) mined by larvæ of *Trachykele nimbosa*. (Photograph by H. E. Burke.) (Original.)

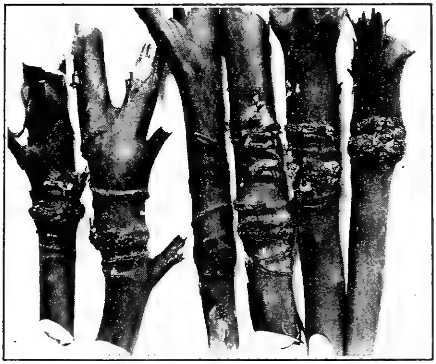


FIG. 3.—Stems from living bush of manzanita (*Arctostaphylos viscida*) showing galls made by mines of larvæ of *Agrilus* sp. ×¼. (Photograph by H. E. Burke.) (Original.)

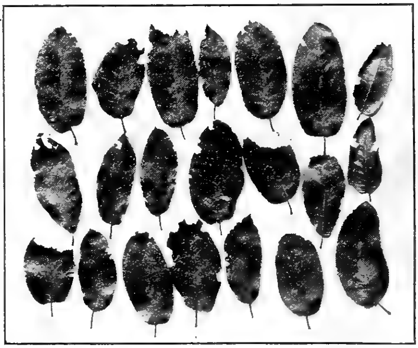


FIG. 4.—Leaves of the live oak (*Quercus wislizeni*) partly eaten by adults of *Agrilus angelicus*. ×¼. (Photograph by H. E. Burke.) (Original.)

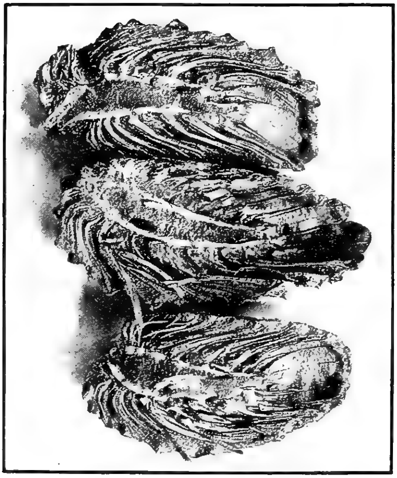


FIG. 5.—Cones of the knobcone pine (*Pinus attenuata*) mined by the larvæ of *Chrysophana placida*. ×½. (Photograph by H. E. Burke.) (Original.)

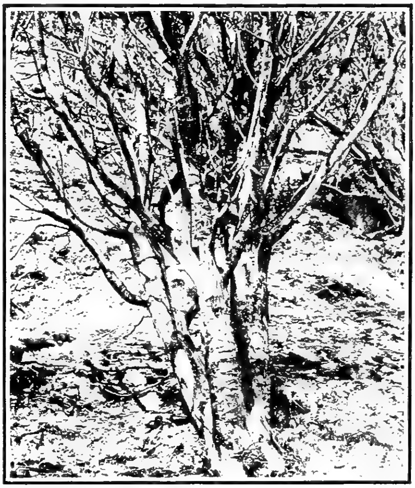
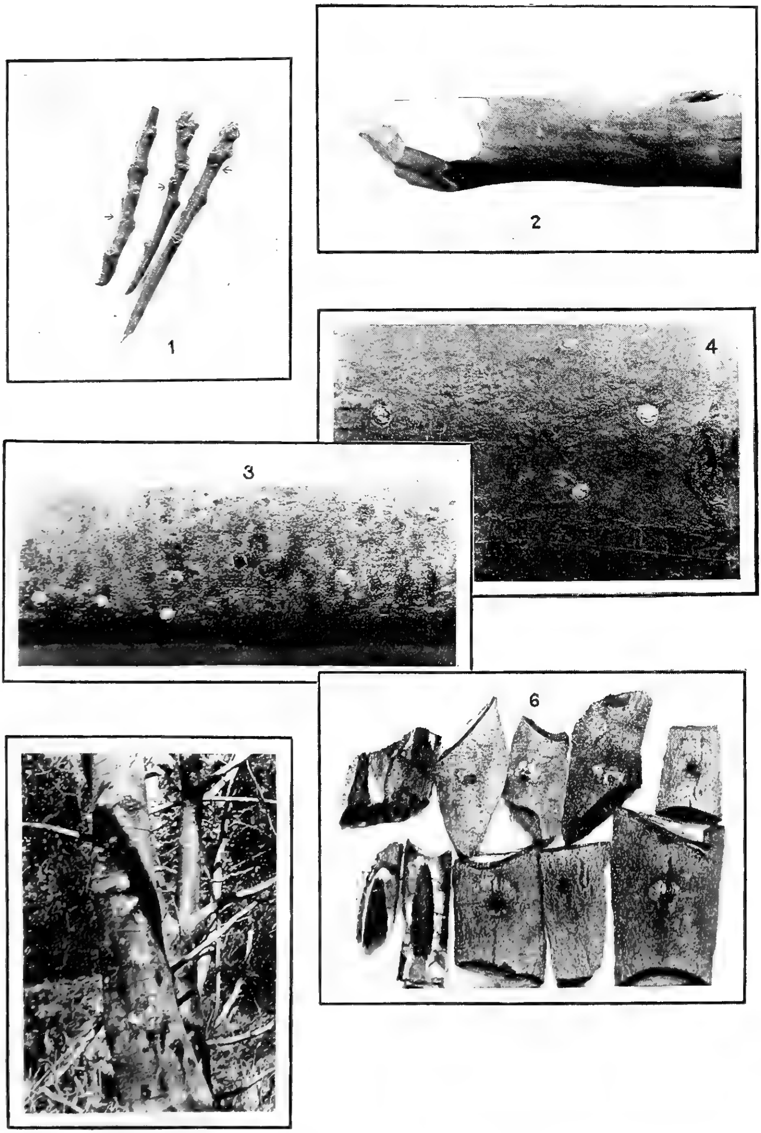


FIG. 6.—Manzanita (*Arctostaphylos viscida*) bush partly killed by mines of larvæ of *Agrilus* sp. ×1/20. (Photograph by H. E. Burke.) (Original.)

WORK OF FLAT-HEADED BORERS.



WORK OF FLAT-HEADED BORERS.

FIG. 1.—Eggs of *Agrilus angelicus* laid singly on twigs of live oak (*Quercus agrifolia*). $\times 1$. FIG. 2.—Egg of *Agrilus* sp. laid singly on stem of manzanita (*Arctostaphylos viscida*). $\times \frac{1}{2}$. FIG. 3.—Egg masses of *Agrilus politus* on bark of stem of arroyo willow (*Salix lasiolepis*). Some covered with the protective covering, some uncovered. $\times \frac{1}{2}$. FIG. 4.—Egg masses of *Agrilus* sp. on bark of trunk of white alder (*Alnus rhombifolia*). $\times \frac{1}{2}$. FIG. 5.—Trunk of living white alder (*Alnus rhombifolia*) showing egg masses of *Agrilus* sp. and the sap flowing from the wounds caused by the feeding of the young larvæ. $\times \frac{1}{24}$. FIG. 6.—Sections from the trunk of a living white alder (*Alnus rhombifolia*) showing old egg masses on the bark, larval work under the bark, and the "craters" formed in the bark when the attack was not severe enough to kill the tree. The brood died in the larval stage and the wound will cause a check in the wood. $\times 1$. (Photographs by H. E. Burke.) (Original.)

faces; true legs wanting; ambulatory tubercles sometimes present; cerci wanting; spiracles crescentic, one large one on either side of the second segment and one small one on either side of each of the fourth to eleventh segments, on the anterior dorso-lateral surface.

Key to Genera of Buprestid Larvæ.[1]

1. First segment distinctly larger and broader than the following segment; larva clublike or pestlelike in form, somewhat flattened; bark and wood miners (Pl. I, fig. 1) 2
   First segment only slightly broader or slightly narrower than the following segment; larva slightly wedge-shaped (cuneiform) or spindle-shaped (fusiform), much flattened; segments deeply notched and lobed; leaf-miners (Pl. VI, figs. 3, 4) 19
2. Last segment without a distinct chitinous fork (Pl. I, fig. 1) 3
   Last segment with a distinct chitinous fork (Pl. VI, figs. 1, 2) 18
3. Plates of first segment with distinct chitinous rugosities (Pl. I, fig. 1) 4
   Plates of first segment without distinct chitinous rugosities, surface sometimes dull, sometimes shining (Pl. IV) 8
4. Rugosities of first segment strongly developed, tending to form ridges; plates with rather definite margins, markings dark and distinct (Pl. I, fig. 1) 5
   Rugosities of first segment pointlike; plates with indefinite margins, markings light, appearing more as grooves than as definite lines (Pl. I, figs. 3, 4) 6
5. Dorsal plate marked by a distinct inverted Y (Pl. I, fig. 1) .... *Chalcophora.*
   Dorsal plate marked by a distinct marking more like an inverted V or U than a Y (Pl. I, fig. 2) .... *Chalcophorella.*
6. Dorsal plate marked by a short, trunked, inverted Y or U, the apex and trunk of which are often faint, rugose area forming more or less of a hood around the Y; ventral plate marked with a median groove that extends from the posterior margin of the plate two-thirds or three-fourths of the distance to the anterior margin, not bisecting the plate (Pl. I, figs. 3, 4; Pl. II, fig. 1) .... *Buprestis.*
   Dorsal plate marked by an inverted V formed from light grooves; ventral plate marked with a median groove that extends from the anterior margin backward, sometimes bisecting the plate (Pl. II, fig. 3) 7
7. Dorsal plate rather oblong; ventral plate quite narrow, almost rectangular, completely bisected by a median groove; first segment not much larger than the second and third, fourth segment as large as the fifth (Pl. II, figs. 2, 3) .... *Melanophila.*
   Dorsal plate circular; ventral plate circular, never completely bisected by the median groove, which extends backward from the anterior margin about two-thirds of the distance to the posterior margin; first segment much larger than the other segments, fourth smaller than fifth (Pl. II, fig. 4; Pl. III, fig. 1) .... *Chrysobothris.*
8. Dorsal plate marked by an inverted V or Y formed of lines or grooves (Pl. III, fig. 2) 9
   Dorsal plate marked by a single median line or groove which may broaden out at either end (Pl. IV, fig. 3) 13
9. Dorsal marking an inverted V of deep grooves, ventral line not bisecting plate, third segment with a pair of ambulatory tubercles above and below, surface shining (Pl. III, fig. 2) .... *Anthaxia.*
   Dorsal marking an inverted V or Y of dark lines, ventral line bisecting plate, surface rather dull (Pl. IV, fig. 2) 10
10. Both dorsal and ventral markings with narrow simple anterior ends (Pl. III, figs. 3, 4) 11
    Both dorsal and ventral markings with broad reticulated anterior ends (Pl. IV, figs. 1, 2) 12
11. Dorsal marking a long trunked inverted Y with a brownish base, ventral marking a straight bisecting line with a brownish anterior end (Pl. III, fig. 3) .... *Cinyra.*
    Dorsal marking an inverted V with a simple apex, ventral marking a simple bisecting groove (Pl. III, fig. 4) .... *Poecilonota.*

[1] So far as determined the characters used in the key hold for larvæ of any stage.

12. Dorsal marking an inverted Y with a depressed shining reticulated diamond-shaped area surrounding the apex (Pl. IV, fig. 2)............ *Trachykele.*
Dorsal marking an inverted V with a broad reticulated apex (Pl. IV, fig. 1) .... *Dicerca.*
13. Dorsal plate rather small, oval or egg-shaped, marked by a distinct brownish median groove which is goblet-shaped in front and forked behind; a pair of brown spots on the median subdorsal areas of the second and third segments (Pl. IV, fig. 3)............................. *Thrincopyge.*
Dorsal plate large, covering most of the dorsal surface, marked by a distinct simple median groove sometimes broadening in front (Pl. IV, fig. 4). 14
14. Ventral plate with a median dark line, both plates slightly corrugated longitudinally, a dark brown sunken spot on either side of the head near the base of the mandible, a pair of brown spots on posterior subdorsal areas of third segment and a pair on anterior ventral area of fourth segment (Pl. IV, fig. 4).. *Polycesta.*
Ventral plate with simple median line or groove, no sunken spots (Pl. V, fig. 1).. 15
15. Fourth segment narrower than fifth (Pl. V, figs. 1, 3)..................... 16
Fourth segment broader than fifth (Pl. V, figs. 2, 4)..................... 17
16. Grooves of first segment light, plates not whitish opaque (Pl. V, fig. 1) .... *Chrysophana.*
Grooves of first segment dark brown, plates whitish opaque (Pl. V, fig. 3) .... *Ptosima.*
17. Third segment narrower than second (Pl. V, fig. 2) .... *Acmaeodera.*
Third segment wider than second, appearing nearly as large as first (Pl. V, fig. 4).. *Tyndaris.*
18. Dorsal plate marked by two moderately separated dark brown lines which converge anteriorly (Pl. VI, fig. 1)......................... *Eupristocerus.*
Dorsal plate marked by a single median bisecting line (Pl. VI, fig. 2).... *Agrilus.*
19. First segment as broad or slightly broader than the following, body gradually tapering to the twelfth, slightly wedge-shaped (Pl. VI, fig. 3)..... *Brachys.*
First segment narrower than the following, body tapering both ways from about the middle, more acute at the posterior end, spindle-shaped (Pl. VI, fig. 4).. *Pachyscelus.*

NOTE.—The author will be glad to determine specimens of "flat-headed borers," and for anyone, if the locality and host plant are given. Such specimens should be sent to Forest Insect Investigations, Bureau of Entomology, Washington, D. C. So far as known no larvæ of the genera *Gyascutus, Hippomelas, Agaeocera, Psiloptera, Xenorhipis, Actenodes, Glyptoscelimorpha, Dystaxia, Schizopus, Mastogenius, Rhaeboscelis,* and *Taphrocerus* have been collected. *Xenorhipis* has been reared from hickory twigs and *Mastogenius* from oak twigs, both in the Southern States, but the larvæ have not been collected.

LIST OF GENERA, DISTRIBUTION, COMMON HABITS, AND HOST TREES.

Chalcophora. Throughout United States, wood-borer in the stump and trunk of injured, dying, and dead trees: Pine (*Pinus*), Douglas spruce (*Pseudotsuga*), and fir (*Abies*).

Chalcophorella (*Texania*). Atlantic States, wood-borer in the stump and trunk of injured, dying, and dead trees: Beech (*Fagus*), oak (*Quercus*), and sycamore (*Platanus*).

Buprestis. Throughout United States, wood-borer in the stump and trunk of injured, dying, and dead trees: Pine (*Pinus*), spruce (*Picea*), Douglas spruce (*Pseudotsuga*), fir (*Abies*), hickory (*Hicoria*), aspen and cottonwood (*Populus*), beech (*Fagus*), chestnut (*Castanea*), oak (*Quercus*), and tulip (*Liriodendron*).

Melanophila. Throughout United States, bark-borer in the stump, trunk, top, and branches of healthy, injured, dying, and dead trees: Pine (*Pinus*), larch (*Larix*), spruce (*Picea*), hemlock (*Tsuga*), Douglas spruce (*Pseudotsuga*), and fir (*Abies*). Kills many trees and causes checks or "gum spots" in the wood of others.

Chrysobothris. Throughout United States, bark and sapwood borer in the roots, stump, trunk, top, and branches of injured, dying, and dead shrubs and trees: Pine (*Pinus*), spruce (*Picea*), Douglas spruce (*Pseudotsuga*), fir (*Abies*), bald cypress (*Taxodium*), incense cedar (*Libocedrus*), cypress (*Cupressus*), juniper (*Juniperus*), butternut and walnut (*Juglans*), hickory (*Hicoria*), willow (*Salix*), aspen, poplar, and cottonwood (*Populus*), birch (*Betula*), alder (*Alnus*), beech (*Fagus*), chestnut (*Castanea*), oak (*Quercus*), elm (*Ulmus*), hackberry (*Celtis*), sweet gum (*Liquidambar*), mountain mahogany (*Cercocarpus*), apple (*Pyrus*), Christmas berry (*Heteromeles*), plum, cherry, and peach (*Prunus*), catsclaw (*Acacia*), mesquite (*Prosopis*), redbud

(*Cercis*), palo verde (*Cercidium*), creosote-bush (*Covillea*), maple (*Acer*), zizyphus (*Zizyphus*), coffee-berry (*Rhamnus*), grape (*Vitis*), ocatillo (*Fouquieria*), basswood (*Tilia*), dogwood (*Cornus*), wild lilac (*Ceanothus*), sour gum (*Nyssa*), and persimmon (*Diospyros*). Kills injured shrubs and trees.

Anthaxia. Throughout United States, bark-borer in trunk and branches of injured, dying, and dead shrubs and trees: Pine (*Pinus*), Douglas spruce (*Pseudotsuga*), fir (*Abies*), hickory (*Hicoria*), willow (*Salix*), oak (*Quercus*), elm (*Ulmus*), mountain mahogany (*Cercocarpus*), service berry (*Amelanchier*), plum (*Prunus*), redbud (*Cercis*), grape (*Vitis*), and paulownia (*Paulownia*). Kills injured shrubs.

Xenorhipis. Southern States, twig-miner in dead twigs: Hickory (*Hicoria*).

Cinyra. Atlantic States, wood-miner in dead limbs: Oak (*Quercus*).

Poecilonota. Throughout United States, bark and wood miner in trunk of injured trees: Willow (*Salix*) and aspen and cottonwood (*Populus*).

Trachykele. Southern, Rocky Mountain, and Pacific States, wood-borer in stump, trunk, and branches of injured, dying, and dead trees: Hemlock (*Tsuga*), fir (*Abies*), bald cypress (*Taxodium*), big tree (*Sequoia*), incense cedar (*Libocedrus*), arborvitae (*Thuja*), cypress (*Cupressus*), and juniper (*Juniperus*).

Dicerca. Throughout United States, wood-borer in the stump, trunk, and branches of injured, dying, and dead shrubs and trees: Pine (*Pinus*), spruce (*Picea*), Douglas spruce (*Pseudotsuga*), fir (*Abies*,) bald cypress (*Taxodium*), butternut (*Juglans*), hickory (*Hicoria*), willow (*Salix*), aspen, poplar, and cottonwood (*Populus*), birch (*Betula*), alder (*Alnus*), beech (*Fagus*), oak (*Quercus*), elm (*Ulmus*), hackberry (*Celtis*), mountain mahogany (*Cercocarpus*), cherry, peach, plum (*Prunus*), sumach (*Rhus*), and poison oak (*Toxicodendron*), maple (*Acer*), buckeye (*Aesculus*), coffee-berry (*Rhamnus*), wild lilac (*Ceanothus*), dogwood (*Cornus*), black gum (*Nyssa*), persimmon (*Diospyros*), ash (*Fraxinus*), and snowberry (*Symphoricarpus*).

Thrincopyge. Southwestern States, wood or pith borer in the flower stem: Yucca, Spanish bayonet, palmio, sotal (*Dasylirion*); nolina (*Nolina*).

Polycesta. Southwestern and Pacific States, wood-borer in the stump, trunk, and branches of injured, dying, and dead shrubs and trees: Cottonwood (*Populus*), alder (*Alnus*), oak (*Quercus*), sycamore (*Platanus*), mountain mahogany (*Cercocarpus*), apple and pear (*Pyrus*), Christmas berry (*Heteromeles*), almond (*Prunus*), catsclaw (*Acacia*), mesquite (*Prosopis*), redbud (*Cercis*), palo verde (*Cercidium*), maple (*Acer*), and manzanita (*Arctostaphylos*).

Chrysophana. Rocky Mountain and Pacific States, wood-borer in stump, trunk, top, and branches of injured, dying, and dead trees: Pine (*Pinus*), hemlock (*Tsuga*), Douglas spruce (*Pseudotsuga*), fir (*Abies*), and arborvitae (*Thuja*). Cone-burrower in cones of knobcone pine (*Pinus attenuata*).

Acmaeodera. Throughout United States, wood-borer in stump, trunk, top, and branches of shrubs and trees: Bald cypress (*Taxodium*), yucca sotal (*Dasylirion*), hickory (*Hicoria*), poplar (*Populus*), alder (*Alnus*), oak (*Quercus*), hackberry (*Celtis*), California laurel (*Umbellularia*), mountain mahogany (*Cercocarpus*), apple and pear (*Pyrus*), service berry (*Amelanchier*), Christmas berry (*Heteromeles*), choke cherry (*Padus*), plum and almond (*Prunus*), redbud (*Cercis*), palo verde (*Cercidium*), ironwood (*Olneya*), lupine (*Lupinus*), china ash (*Melia*), poison oak (*Toxicodendron*), zizyphus (*Zizyphus*), coffee-berry (*Rhamnus*), wild lilac (*Ceanothus*), manzanita (*Arctostaphylos*), and yerba santa (*Eriodictyon*).

Tyndaris. Southwestern States, wood-borer in roots, trunk, and branches of injured, dying, and dead shrubs and trees: Catsclaw (*Acacia*), mesquite (*Prosopis*), and ironwood (*Olneya*).

Ptosima. Atlantic States, wood-borer in stump, trunk, top, and branches of injured, dying, and dead shrubs: Redbud (*Cercis*).

Mastogenius. Southern States, twig-borer in fire-killed saplings: Spanish oak (*Quercus*).

Eupristocerus. Atlantic States, bark-borer in branches of living shrubs and trees: Alder (*Alnus*). Causes the formation of enlarged growths (galls).

Agrilus. Throughout United States, bark and wood borer in roots, stump, trunk, top, and branches of healthy, injured, dying, and dead shrubs and trees: Butternut and walnut (*Juglans*), hickory (*Hicoria*), willow (*Salix*), aspen, poplar, cottonwood, and Balm of Gilead (*Populus*), birch (*Betula*), alder (*Alnus*), ironwood and hornbeam (*Ostrya*), beech (*Fagus*), chestnut (*Castanea*), oak (*Quercus*), hackberry (*Celtis*), mulberry (*Morus*), raspberry and blackberry (*Rubus*), apple (*Pyrus*), serviceberry (*Amelanchier*), catsclaw (*Acacia*), coffee-tree (*Gymnocladus*), locust (*Robinia*), sumach (*Rhus*), maple (*Acer*), dogwood (*Cornus*), madrone (*Arbutus*), manzanita (*Arctostaphylos*), aster (*Aster*), and sagebrush (*Artemisia*). Kills many shrubs and trees, often causing the formation of galls and checks in the wood.

Brachys. Eastern and Central States, leaf-miner in leaves: *Populus*?, alder (*Alnus*), *Fagus*?, chestnut (*Castanea*), oak (*Quercus*), *Ulmus*?, and *Acer*?.

Pachyscelus. Eastern States, leaf-miner in leaves: *Hicoria*?, *Quercus*?, and *Lespedeza*.

NOTE.—Host tree as given indicates, for bark and wood borers, that borer was actually taken from bark and wood and not that the adult was resting on the bark or wood.

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BULLETIN No. 438

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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THE PEAR LEAF-WORM.

By R. L. Nougaret, *Entomological Assistant,* and W. M. Davidson and E. J. Newcomer, *Scientific Assistants, Deciduous Fruit Insect Investigations.*

CONTENTS.

	Page.		Page.
Introduction	1	Biology	9
History and distribution	1	Natural control	17
Possible origin	2	Remedial measures	18
Character and extent of injury	3	Summary	22
Description and habits	4	Bibliography	23

INTRODUCTION.

The pear leaf-worm, more scientifically termed the pear sawfly (*Gymnonychus californicus* Marlatt), is an hymenopterous insect belonging to the family Nematidæ and to the subfamily Nematinæ. For several years it has been noted as a pest on pear trees on the Pacific coast. The observations and experiments recorded herein were made in California by Messrs. R. L. Nougaret and W. M. Davidson, during the years 1911 to 1914, inclusive, and in the State of Washington by Mr. E. J. Newcomer, during the seasons 1914 and 1915.

The injury is caused almost entirely by the feeding of the green wormlike larva and is confined to the foliage, resulting in partial defoliation.

In the localities in which it occurs the insect is quite abundant. Occasionally it becomes a pest of serious consequence, and under favorable conditions it might cause widespread damage.

HISTORY AND DISTRIBUTION.

The pear leaf-worm was described from 1 female collected at Brockport, N. Y., and 10 females taken near Sacramento, Cal., by

Note.—This bulletin is of interest to pear growers generally, but especially to those of the Pacific coast.

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Matthew Cooke (1)[1] in the year 1881. At that time it was reported also from Natoma and Santa Clara, Cal. In the spring of 1909 it was quite common in the vicinity of Stanford University, Cal., and in 1911 it was a pest in Tehama County, Cal., besides being generally distributed throughout the central counties, both on the coast and in the great interior valleys of Sacramento and San Joaquin? (3) As to neighboring States, Prof. H. F. Wilson, of the University of Wisconsin, in a letter reports the insect attacking pear foliage in Oregon (1913); Dr. A. W. Morrill, State entomologist of Arizona, states in a letter that Arizona is free from the insect (1913); Prof. C. P. Gillette states that the insect does not appear to live in Colorado. In Washington it was found in pear orchards in the Wenatchee Valley in 1914 and 1915, being particularly abundant in an orchard about 6 miles from Wenatchee, but careful inquiry did not lead to the discovery of other orchards having more than a scattering infestation.

Mr. C. L. Marlatt, in describing this insect, states that Dr. J. A. Lintner, former State entomologist of New York, reported an undetermined sawfly larva as being injurious to pear in a nursery at Geneva, N. Y., in May, 1894. Mr. Marlatt says (2)[1] it is probable that this is the same species, but as it has not been reported since, so far as known, the identification of the Geneva specimens remains doubtful; however, the collection of a specimen at Brockport, N. Y., indicates that it may be found in the East.

POSSIBLE ORIGIN.

An attempt was made in Washington to ascertain the natural hosts of the pear leaf-worm. The fact that it is found in various localities throughout a range of a thousand miles would indicate that it is a native species. Two wild plants related to the pear are to be found in the vicinity of Wenatchee, Wash. These are the service berry (*Amelanchier cusickii* Fern.) and the thorn apple (*Crataegus brevispina* Dougl.). Plants of both species were searched carefully for larvæ of the sawfly several times in May. Nothing was found on the service berry, but the thorn apple yielded a number of green larvæ very similar to those on pear. They differed, however, in being a more shiny green, and in having scattered brown dots laterally and dorsally on the thorax. A number of these were reared, but the adults have not yet emerged. It is very probable that they belong to a distinct but closely related species.

Nearly full-grown larvæ of the pear leaf-worm were placed upon twigs of both the service berry and the thorn apple. Those on the former fed a little, but soon dropped off and died, while the larvæ on the latter at once began to feed, and several of them matured and spun cocoons. From this it may be inferred that the pear leaf-

[1] Figures in parenthesis refer to "Bibliography," p. 23.

worm may naturally feed upon the thorn apple, and if a native of the Pacific coast there probably exists another host to which it is adapted, and its habit of feeding upon pear may be an acquired one. This is not impossible, as various species of Crataegus and of Sorbus occur throughout the known range of the species.

CHARACTER AND EXTENT OF INJURY.

The injury caused by the pear leaf-worm (fig. 1) is confined among economic plants to the foliage of the pear and is due chiefly to the larva. While it consists primarily in the eating out of circular or semicircular holes in the leaf (fig. 1, *a*, *b*), often whole leaves are eaten down to the petiole. During its period of life a single larva eats about one-fourth of an average-sized pear leaf, so that it requires several larvæ to consume such a leaf entirely. When two or more larvæ are feeding simultaneously on the same leaf they frequently cut the midrib in two at about the middle of the leaf, and the portion thus cut off falls to the ground. Severe infestations cause the defoliation of branches (Pl. II, fig. 2). The larvæ are not addicted to roaming and commonly do not leave their original leaf as long as any edible part of it remains. In Washington many trees were observed in 1914 that were from one-third to nearly one-half defoliated. Such infestations, however, are not common. The lower parts of large trees are the more heavily infested.

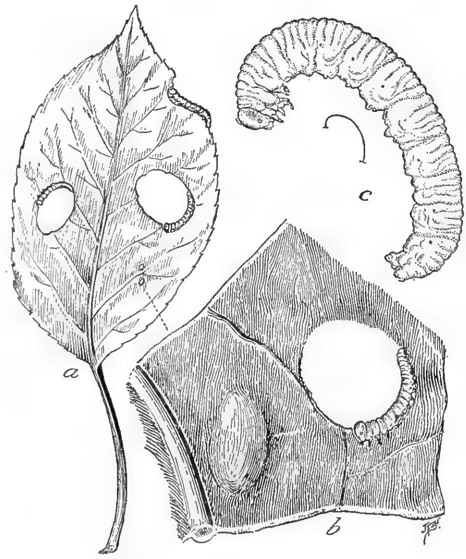


FIG. 1.—The pear leaf-worm (*Gymnonychus californicus*): *a*, Leaf showing character of injury and egg in situ; *b*, enlarged section of leaf showing egg in tissue and manner of feeding of young larva; *c*, full grown larva. *a*, Slightly enlarged; *b*, *c*, much enlarged. (Original.)

The eggs are usually laid in leaves that are not yet unrolled, and those which fail to hatch often deform or curtail the growth of the leaf, possibly by cutting off its food supply between the point where the egg was deposited and the edge of the leaf, making the latter one-sided (Pl. I, fig. 3). When the eggs hatch normally this malformation does not occur. The puncture of the ovipositor frequently causes a discoloration of the adjacent tissues and sometimes wilts young, tender leaves.

The larva apparently will eat the foliage of all cultivated varieties of pear.

DESCRIPTION AND HABITS.

THE EGG.

The egg (fig. 1, *a*, *b*) appears on the surface of the leaf as a small oval blister of a greenish color. It is reniform, slightly smaller at one end, translucent greenish, and about 0.75 mm. in length and 0.50 mm. in maximum width. As the margins of the egg are more or less covered by the edges of the ruptured epidermis of the leaf to which it adheres, it is hard to remove the egg intact. This incised part of the leaf epidermis appears as a narrow brownish area surrounding the egg. On the lower surface of the leaf nothing is visible but a dark spot, indicating the passage of the ovipositor. The egg is slightly more oval than that of the pear slug (*Caliroa cerasi* L.), which it greatly resembles.

As many as 20 eggs have been found in a single leaf, but ordinarily, even upon a heavily infested tree, there are not more than three or four and more often only one or two.

Just before the egg hatches the whitish curved embryo with its pink "eyespots" is visible through the shell.

The manner of oviposition is described later in this section under the heading of "The adult."

THE LARVA.

The larva emerges through the epidermis of the underside of the leaf, apparently crawling out through the incision made by the adult in depositing the egg. The newly hatched larva measures 1.3 mm. to 1.7 mm. in length, and has an average width of 0.35 mm. As soon as its head is free of the shell the larva begins to feed, cutting a small round hole in the leaf. By the time the larva has fully emerged, the hole or opening is large enough to permit the true legs to grasp the edge, and as the hole is enlarged the whole body is drawn in so that it lies in a curved position around the edge. The true legs are gray, quite long, and are fitted for straddling the edge of the leaf and not for walking over the surface. After a few hours of feeding the color of the food begins to show through the body, and the head and true legs become olive brown. There are seven pairs of prolegs, which like the body are pale whitish or greenish-white.

Molting takes place on the edge of the hole eaten out of the leaf wherever the larva happens to be in the course of its feeding. The larva crawls out of the old skin and soon resumes its feeding. The skin usually adheres to the leaf for a time and is not eaten. After the first molt the larva has a length of from 2 to 3 mm. Just after molting the appearance is much as before, except that the head is larger in proportion to the body and both it and the true legs are of a lighter green than the body, which latter is considerably wrinkled and slightly flattened, especially at the caudal end. Later the head changes to light brown and the wrinkles disappear as the body fills out. After the second molt the average length is about 6 mm. The head appears green and toward the end of the instar is lightly dotted with small brown spots. The folds or wrinkles in the cuticle and sutures appear as white stripes and spots. The length after the third molt is 9.2 mm. While at first the larva is similar in appearance to the preceding instar, the color later is bluish green with whitish lateral and dorsal stripes, due to the folds of the skin. These whitish stripes disappear at maturity, when the folds have become filled out. By the time the larva has cast its first skin (on the average $5\frac{1}{2}$ days after hatching) it has eaten a hole with average diameter of 3.8 mm. After the second molt (on the average $8\frac{1}{2}$ days after hatching) it has eaten out an area of about 12 mm. diameter. Four larvæ were found to have eaten during their larval existence 514, 241, 280, and 416 sq. mm. of leaf, respectively, the first of these having consumed somewhat more than one-fourth of an average-sized pear leaf (Bartlett).

It was found that a considerable percentage of larvæ died at the time of their emergence because they were unable to cut their way through the eggshell or through the leaf. Also during the first instar there was considerable mortality due to unknown causes. During the operation of molting numbers fall to the ground, because the larva retains only a precarious foothold at this time and is easily shaken or knocked off.

The width of a strip of leaf eaten by the larva during one of its circular trips around the hole is equal to three-fourths the height of its head. It eats as far as it can reach forward without advancing. The head of the larva is always closely in contact with the leaf, filling up the place of that portion eaten away, as does also its body, which lies at full length along the edge of the hole (fig. 1, *b*). It is for this reason that the edge of the leaf, defining the hole, appears to be an uninterrupted line, and the larva, being almost the color of the leaf, is not readily detected without close examination, but its presence is made known by the characteristic circular holes that it cuts in the leaves. In feeding the larva holds the posterior end of the body either straight along the edge of the opening or curled about it, and eats around and around the hole, which becomes gradually larger. Where the larvæ are numerous and two or more feed on the same leaf they may soon consume it entirely, whereupon they migrate to other leaves and commence feeding on the edges (fig. 1, *a*), as they are unable to eat through the flat surfaces. The larvæ feeding along the edges of the leaves on the lower part of the tree are mostly those which drop down from above, being dislodged at the time of molting or from some other cause. While migrating along the leaf petioles or the edges of the leaves the posterior part of the body is carried in a characteristic curled position, and when the larva is disturbed this posterior curled part is thrown up in a threatening manner.

The full grown larva (fig. 1, *c*) measures 12 mm. (0.5 inch) in length and 1.6 mm. in width. The head is light green, dotted antero-dorsally with small brown dots. Upon closer examination these dots are seen to be divided into two or three parts which fit closely together. The eyes are black; the mouth parts dark brown, and the clypeus light brown with a narrow inverted V-shaped band of green between it and the dotted area, which latter extends from the eyes back to the insertion of the head into the thorax and is divided dorso-frontally by a narrow green line. Ordinarily the larva when full grown drops to the ground, but some have been noticed crawling about the trunks of the trees as though crawling to the soil. This is unusual, however, and probably occurs with those larvæ that happen to have been feeding near the main trunk. Just before the larva is ready to drop to the ground for "cocooning," the caudal segments turn yellowish.

THE COCOON AND PUPA.

The cocoon (fig. 2; Pl. I, fig. 4) is cylindrical; slightly constricted at the middle, rounded at the ends and somewhat larger at one end than at the other. It is closely woven of fine silk, smooth inside and roughened or with a pebbled appearance, due to the adherence of small bits of soil, outside. It is at first light greenish and if kept dry remains a straw color, but if moistened, as it usually is when spun in the soil, it soon darkens, becoming a dark brown. Some larvæ spin a quantity of loose, red-brown silk about the outside before spinning the light-green cocoon, especially if the cocoon happens to be spun among old leaves in the soil, and an occasional cocoon is found which is entirely of this red-brown color. The larva lies with its head in the small end of the cocoon, and the posterior part of the body curled up in the larger end. In Washington the average length of 20 cocoons was 5.7 mm. and the average maximum width 3 mm. In California the measurements of both width and length were slightly in excess of this.

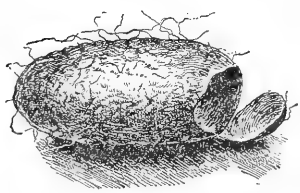


FIG. 2.—Pear leaf-worm: Cocoon. Much enlarged. (Original.)

The habit of cocooning in the soil seems to be for protection rather than for the effect of moisture. Cocoons spun in dry glass vials in May, 1914, gave adults in April, 1915, though they had been kept perfectly dry during the intervening 11 months. The cocoon is closely spun and very tough and undoubtedly prevents the evaporation of any moisture from the inclosed larva. Most of the larvæ spin their cocoons within an inch of the surface, and during the long dry summers of California and Washington this top inch of soil is subjected to a large amount of heat and desiccation. Thus it is evident that the larva and its cocoon must be able to withstand considerable dryness. An experiment was performed at Wenatchee, Wash., to learn whether moisture was necessary to the larva. Cocoons were collected from the soil within a few days after they were spun, in May, 1914, and divided into two lots, both of which were kept on the surface of some soil in jelly glasses. The soil in one lot was kept moist by pouring water through a glass tube inserted in the soil. The other lot was allowed to remain dry. The first lot was kept moist until September. After this both lots were left untouched until spring, being kept over winter in an unheated room. During the emerging period the first lot was again kept moist, while the other remained dry as before. As a check on these lots the emergence from a third lot, collected April 3, 1915, was recorded. Table I gives the results of this experiment:

TABLE I.—*Adult emergence of pear leaf-worm from moist and dry cocoons, Wenatchee, Wash., April, 1915.*

Observation.	Moist.	Dry.	Cocoons collected Apr. 3, 1915.	Total.
Number of cocoons	59	194	55	308
Number emerged	51	118	31	200
Per cent emerged	86.4	60.8	56.4	64.9

From Table I we learn that 86.4 per cent emerged from cocoons kept moist during the previous summer, 60.8 per cent from dry cocoons, and 56.4 per cent from the cocoons collected April 3, 1915, and which were thus under natural conditions during practically the whole period; the total percentage emerging was 64.9. The cocoons of the dry lot that did not give adults were examined later, and a number of them contained fully-formed adults that had been unable to break through the tough, dry cocoon. This indicates that the smaller percentage of adults emerging from these cocoons was due to the dryness at the time of emergence rather than the dryness during the preceding summer, and perhaps collective dryness weakened the insects somewhat. The larvæ had lived through the dry period of the summer, had pupated the following spring, and the adults had cast the pupal skin, but had been unable to get through the dry cocoon.

The smaller emergence from cocoons collected in April, 1915, is explained by the more uneven conditions to which they had been subjected, such as the freezing and thawing of winter.

The newly-molted pupa is entirely pale green, with black eyes, and measures about 5 mm. by 1.7 mm. Shortly before the time for the adult to emerge the pupa turns dusky blackish, with the wings, forelegs, and portions of middle and hind legs yellowish. Ventrally the abdominal rings and the saw case of the female are greenish.

THE ADULT.

Female.—Length 4.5 mm., very short and robust, shiny; head densely punctured, rather opaque; clypeus very slightly emarginate; frontal wanting or very slightly indicated; antennæ very short, not as long as head and thorax, filiform, third joint longest; intercostal nearly at right angles with costa, interstitial with basal; venation otherwise normal; stigma short, broadly ovate at base; apex of costa strongly thickened; sheath broad, slightly emarginate beneath and acuminate at tip; claws simple. Color black; angles of pronotum, tegulæ, trochanters, apices of femora (particularly anterior pair), tibiæ, and tarsi yellowish ferruginous; the posterior tibiæ and tarsi particularly somewhat infuscated; veins, including stigma and costa, dark brown; wings hyaline.

The females are more robust than the males. Upon issuing from the cocoon the adult cuts a small circular hole almost all the way around the end of the cocoon and issues by pushing up this "lid." Adults (fig. 3) fly preferably in the full sunshine, but also in cloudy weather. Their flight is jerky, and when captured they feign death. A great amount of time is spent running about over the unfolding leaves and buds, the antennæ vibrating incessantly. They take food from the

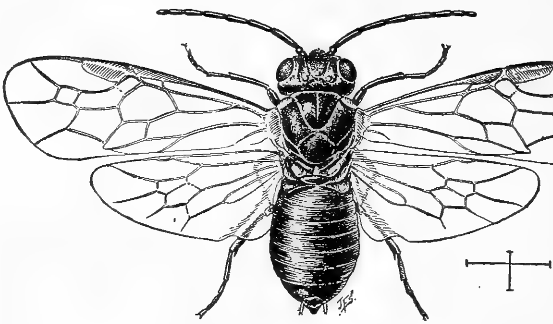
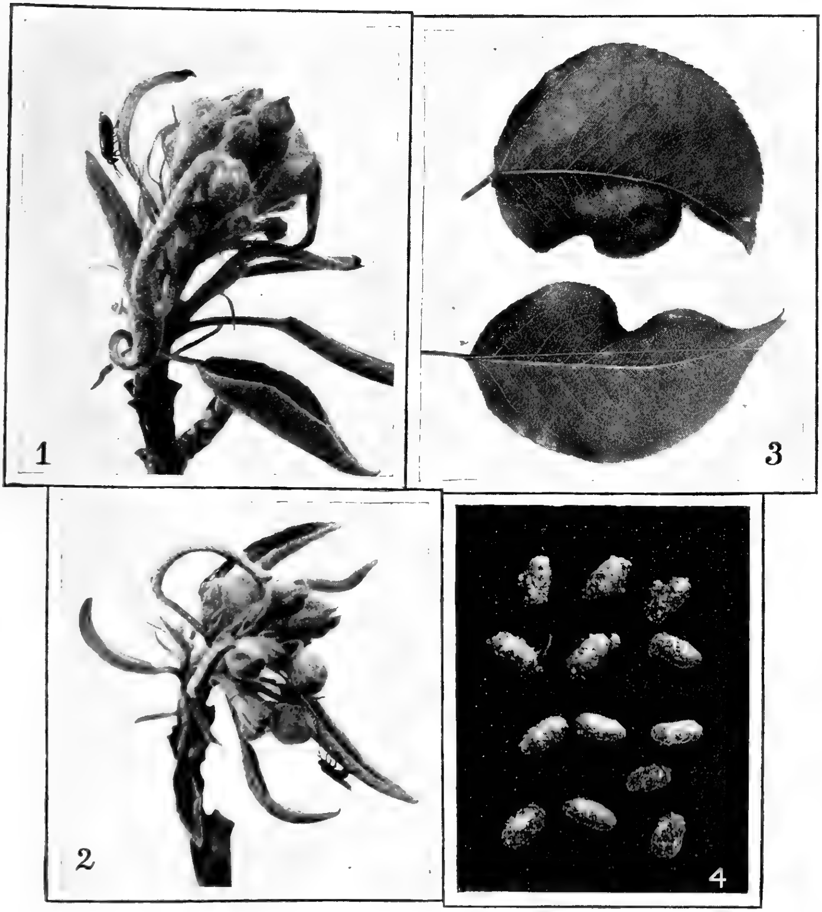


FIG. 3.—Pear sawfly, the adult of the pear leaf-worm. Much enlarged. (Original.)

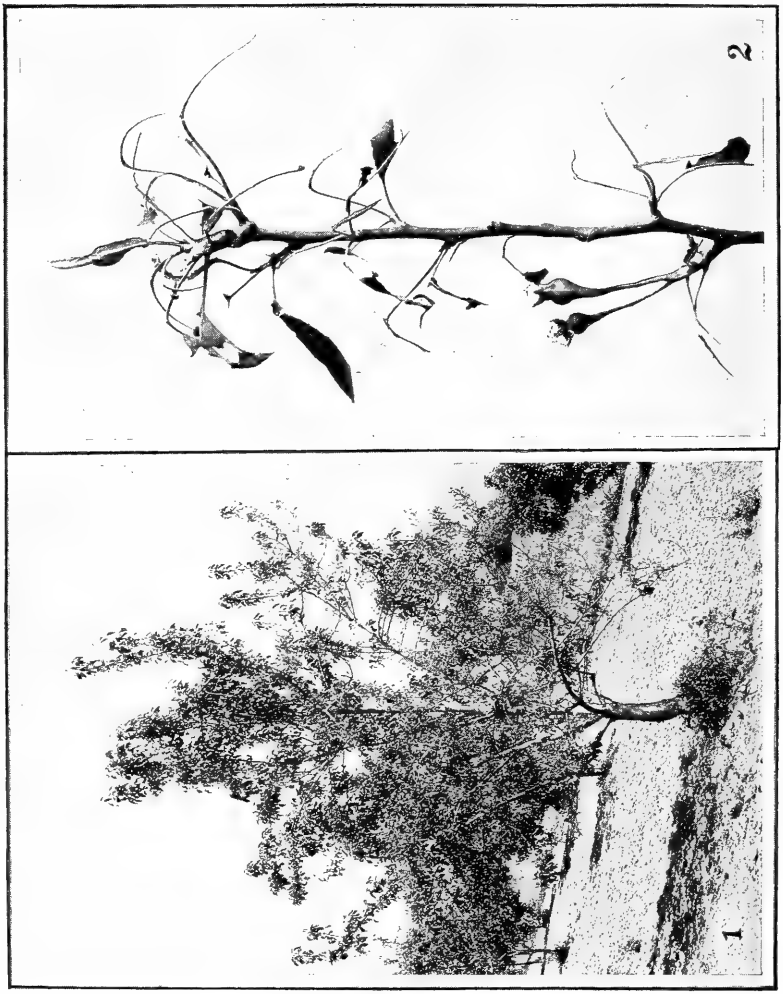
nectaries of the leaves, and from observations it appears probable that they also make slight incisions with the ovipositor and suck up the moisture which collects at these wounds. (Pl. I, fig. 1.)

When ovipositing they run about in the same way, and at intervals the abdomen is bent down and the tip of the ovipositor inserted in the leaf, always on the under side, the leaves being mostly as yet unrolled. Sometimes the place selected appears to be unsuitable, for the ovipositor is withdrawn after several seconds and inserted in another place (Pl. I, figs. 1, 2). The whole process of oviposition occupies a little less than two minutes. The ovipositor (fig. 4) normally lies in its sheath, point up, and the abdomen must be curved under, so that the point, which is extruded a little way, may be inserted into the leaf. The saws immediately begin to work back and forth, and after about 30 seconds the ovipositor has been driven far enough into the leaf epidermis so that it no longer needs the support of the sheath. At this juncture the abdomen is straightened out, leaving the ovi-



THE PEAR LEAF-WORM.

FIG. 1.—Adult female feeding. FIG. 2.—Adult female ovipositing. FIG. 3.—Leaves deformed by oviposition. FIG. 4.—Cocoons. (Original.)



WORK OF THE PEAR LEAF-WORM.

FIG. 1.—Pear tree; left side sprayed; right side unsprayed, badly defoliated. FIG. 2.—Pear twig showing defoliation by larvæ. (Original.)

positor at right angles to the sheath (fig. 4, *a*). The rhythmical sawing goes on for about 50 seconds more, the two surfaces of the leaf being forced apart to form a more or less oval cavity. The sawing ceases, and the portion of the ovipositor still outside the leaf is seen to become more opaque and greenish. This is due to the passage of the egg and the mucilaginous matter around it. The abdomen moves up and down slightly as the egg is forced into the cavity, and the saws are removed gradually. The actual depositing of the egg occupies about 30 seconds, and as soon as the ovipositor is free the antennæ, which have been practically quiet during the whole operation, immediately resume their rapid vibrations, and the fly moves to a

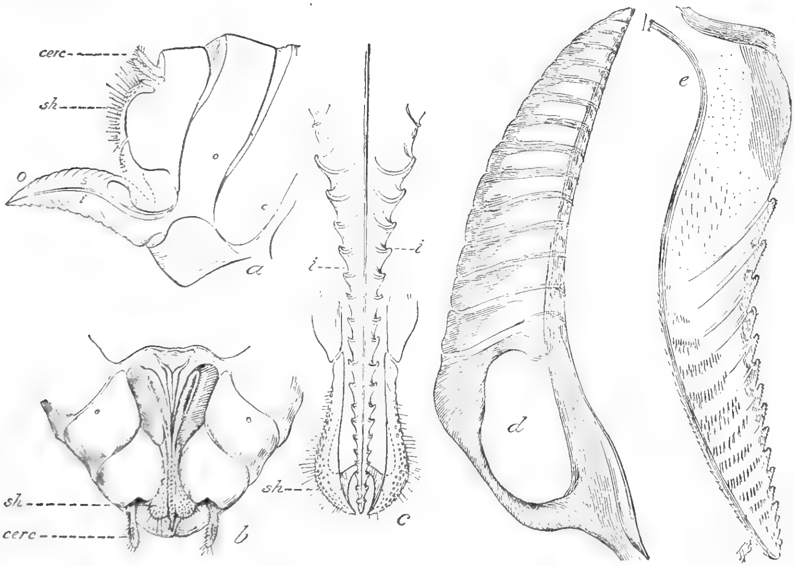


FIG. 4.—Ovipositor of adult female of the pear sawfly: *a*, Last three abdominal segments with ovipositor protruding; *b*, ventral view of last segments of abdomen with ovipositor retracted within its sheath; *c*, ventral view of ovipositor and portion of sheath, showing lateral ridges on inferior blades; *d*, single superior saw blade; *e*, single inferior saw blade; *o*, ovipositor; *s*, superior saw blade; *i*, inferior saw blade; *sh*, sheath; *cerc*, cerci. All highly magnified. (Original.)

new place. One female was observed to deposit 5 eggs in 20 minutes, but not all in the same leaf.

BIOLOGY.

There is one generation annually. In California, from observations made in 1912 and 1913, it was found that adults issued during March and the first half of April, but before the middle of March very few emerged. In Washington, in the spring of 1915, practically all the adults emerged between the 1st and 15th of April. In both localities the period of emergence probably varies more or less with the season.

Immediately after issuing, the sexes presumably mate and the females oviposit on young pear leaves.

THE EGG.

In California, in Santa Clara County, in 1912, eggs were first observed on trees as early as March 23, and in Contra Costa County, in 1913, as early as March 25. During the last few days of March in both these years oviposition was observed. In Washington, in 1915, numerous females were observed in the Zimmerman orchard on April 7, though none had been found 3 days before. None was seen to oviposit on this date, and they were evidently all very recently emerged. A week later the period of oviposition was at its height and by April 24 most of the adults had disappeared. The adults prefer to oviposit on those varieties of pears which leaf out early and generally select for oviposition a young leaf not yet unrolled. In California the earliest adults generally find the Bartlett not far enough advanced, and so the earliest eggs are deposited on other varieties. Ovipositing females kept in a jar were provided with cherry and plum leaves, but they refused these as hosts, although, in similar confinement, they oviposited regularly in pear leaves.

Table II indicates the incubation period in California for 85 eggs:

TABLE II.—*Incubation record of eggs of the pear leaf-worm, Walnut Creek, Cal., 1913.*

Number of eggs deposited.	Date of deposition.	Date of hatching.	Number hatched.	Incubation stage.
				Days.
118	Mar. 29	Apr. 7	23	9
		Apr. 8	6	10
		Apr. 9	21	11
		Apr. 10	28	12
		Apr. 11	5	13
		Apr. 12	2	14

For this experiment 20 adults were confined in a cage in which a growing pear limb was inclosed. The average incubation stage was 11.1 days. Out of 118 eggs deposited, 85, or 72 per cent, hatched.

Table III indicates the incubation period, in Washington, of 23 eggs deposited by a single unfertilized female on a pear twig kept in water.

TABLE III.—*Incubation record of eggs of the pear leaf-worm, Wenatchee, Wash., 1915.*

Number of eggs deposited.	Date of deposition.	Date of hatching.	Number hatched.
47	Apr. 11–14	Apr. 19	10
		Apr. 20	4
		Apr. 21	1
		Apr. 22	1
		Apr. 23	6
		Apr. 24	1

Another lot, deposited from April 8 to 11, began hatching April 18. The incubation period was thus 8 to perhaps 12 or 13 days. The twig above cited was badly wilted by the 24th, after only 50 per cent of the eggs had hatched, and none hatched after this date. It is probable that under normal conditions hatching would have been more regular, and also that the average incubation period would have been lengthened. It was observed that unfertilized eggs hatched as readily as fertilized ones. The life-history phase of parthenogenesis is considered farther on in this chapter in the discussion of the adult.

THE LARVA.

In the field at Walnut Creek, in 1913, the first larva was observed on April 1. It was about 3 days old. Two days later about 1 per cent of the eggs already laid had hatched. At Red Bluff, Tehama County, Cal., in 1911, most of the larvæ were half grown on April 9, and in 1912 full-grown larvæ were found at Red Bluff April 22, and on May 12 no more larvæ could be found.[1] At Suisun and Courtland, Cal., in 1912, the first larvæ went to the ground about April 10, but at San Jose not before May 1. In 1913, at Walnut Creek, the first larvæ went to the ground about April 20, and after May 10 very few larvæ remained on the trees. It appears that in the interior valleys, where the pear trees move earlier, the sawflies emerge and the larvæ mature earlier than in the coastal districts. This is doubtless due to climatological influences.

The first molt is cast from 3 to 8 days after hatching, the second molt from 2 to 7 days after the first, the third molt from 2 to 7 days after the second, and from 4 to 10 days elapse between the date of the third molt and maturity of the larva, the variations being chiefly due to temperature influences. The pupal molt does not take place until the following spring or shortly before the issuance of the adult. Table IV indicates the larval life observed at San Jose, Cal., in 1912.

TABLE IV.—*Larval stages of the pear leaf-worm, San Jose, Cal., 1912.*

No.	Date egg hatched.	Date larva spun cocoon.	Active larval life.	No.	Date egg hatched.	Date larva spun cocoon.	Active larval life.
			Days.				*Days.*
1	Apr. 7	May 9	32	10	Apr. 12	May 15	33
2	...do.....	May 10	33	11	Apr. 13	May 12	29
3	...do.....	May 12	35	12	...do.....	May 14	31
4	Apr. 8	May 11	33	13	...do.....	...do.....	31
5	...do.....	...do.....	33	14	...do.....	May 16	33
6	Apr. 9	May 9	30	15	...do.....	May 18	35
7	Apr. 10	May 17	37	16	Apr. 17	May 13	26
8	Apr. 12	May 10	28	17	May 2	May 31	29
9	...do.....	May 11	29				

[1] Letter from Mr. C. B. Weeks, Tehama County horticultural commissioner.

Thus the maximum larval life was 37 and the minimum 26 days. The average is found to be 31.6 days. In this experiment the larvæ were kept in glass vials, but in the experiment of which the results are given in Table V the larvæ were allowed to remain on the tree until a day or two before they went to the soil, a small numbered cloth tag attached to each leaf permitting accurate observation on each larva. The observations recorded in Table V are, therefore, more normal than those indicated in Table IV.

TABLE V.—*Larval stages of the pear leaf-worm, Walnut Creek, Cal., 1913.*

No.	Date of—					Length of instars in days.				Total.
	Hatching.	Molt 1.	Molt 2.	Molt 3.	Spinning cocoon.	1	2	3	4	
1	Apr. 13	Apr. 19	Apr. 24	Apr. 28	May 2	6	5	4	4	19
2	...do.....	Apr. 20	...do.....	...do.....	May 3	7	4	4	5	20
3	...do.....	...do.....	...do.....	...do.....	...do.....	7	4	4	5	20
4	...do.....	Apr. 21	...do.....	...do.....	May 4	8	3	4	6	21
5	...do.....	...do.....	...do.....	...do.....	May 5	8	3	4	7	22
6	...do.....	Apr. 19	...do.....	(?)	May 1	6	5	(?)	7	18
7	...do.....	Apr. 20	(?)	Apr. 26	May 3	7	(?)	(?)	7	20
8	Apr. 14	Apr. 19	Apr. 23	(?)	...do.....	5	4	(?)	(?)	19
9	...do.....	Apr. 20	...do.....	Apr. 26	May 4	6	3	3	8	20
10	...do.....	...do.....	...do.....	Apr. 29	May 3	6	3	6	4	19
11	...do.....	Apr. 21	Apr. 24	Apr. 27	May 4	7	3	3	7	20
12	...do.....	...do.....	...do.....	Apr. 28	May 3	7	3	4	5	19
13	...do.....	...do.....	...do.....	...do.....	May 4	7	3	4	6	20
14	Apr. 15	Apr. 20	...do.....	(?)	...do.....	5	4	(?)	(?)	19
15	...do.....	Apr. 21	...do.....	Apr. 30	May 7	6	3	6	7	22
16	Apr. 16	Apr. 20	Apr. 23	Apr. 25	Died.	4	3	2	......	......
17	...do.....	...do.....	Apr. 24	Apr. 26	May 3	4	4	2	7	17
18	...do.....	Apr. 22	...do.....	Apr. 28	May 4	6	2	4	6	18
19	...do.....	...do.....	Apr. 25	Apr. 27	May 5	6	3	2	8	19
20	...do.....	...do.....	...do.....	Apr. 30.	May 9	6	3	5	9	23
21	Apr. 17	...do.....	...do.....	...do.....	Died.	5	3	5	......	......
22	...do.....	Apr. 23	...do.....	Apr. 28	May 6	6	2	3	8	19
23	...do.....	...do.....	...do.....	Apr. 30	May 6	6	2	5	6	19
24	...do.....	...do.....	Apr. 26	May 2	May 8	6	3	6	6	21
25	Apr. 18	...do.....	Apr. 25	Apr. 30	May 5	5	2	5	5	17
26	...do.....	...do.....	...do.....	...do.....	May 6	5	2	5	6	18
27	...do.....	...do.....	...do.....	...do.....	May 8	5	2	5	8	20
28	...do.....	...do.....	Apr. 26	Apr. 29	May 9	5	3	3	10	21
29	...do.....	Apr. 24	...do.....	...do.....	May 8	6	2	3	9	20
30	Apr. 19	...do.....	...do.....	Apr. 28	Died....	5	2	2	......	......
31	...do.....	...do.....	...do.....	May 2	May 7	5	2	6	5	18
32	...do.....	...do.....	Apr. 28	...do.....	May 12	5	4	4	10	23
33	Apr. 20	...do.....	Apr. 26	Apr. 28	May 8	4	2	2	10	18
34	...do.....	...do.....	Apr. 28	May 5	Died.	4	4	7	......	......
35	Apr. 21	...do.....	Apr. 27	May 2	May 8	3	3	5	6	17
36	...do.....	...do.....	...do.....	May 3	May 10	3	3	6	7	19
37	...do.....	...do.....	Apr. 28	May 1	May 9	3	4	3	8	18
38	...do.....	...do.....	...do.....	May 4	...do.....	3	4	6	5	18
39	...do.....	Apr. 25	Apr. 29	...do.....	...do.....	4	4	5	5	18
40	...do.....	...do.....	May 1	May 6	May 13	4	6	5	7	22
41	Apr. 22	...do.....	Apr. 29	May 2	May 8	3	4	3	6	16
42	...do.....	Apr. 26	May 2	May 6	May 14	4	6	4	8	22
43	Apr. 23	...do.....	...do.....	...do.....	May 12	3	6	4	6	19
44	...do.....	...do.....	May 3	...do.....	...do.....	3	7	3	6	19
45	...do.....	Apr. 30	May 4	May 9	May 14	7	4	5	5	21
46	Apr. 25	May 1	May 6	May 10	May 16	6	5	4	6	21
47	May 7	May 14	May 17	May 22	May 27	7	3	5	5	20

Out of the 47 individuals recorded in Table V, it will be noticed that 4 died after completing their third molt. These 4 were full grown and died from their inability to spin cocoons, and it appears that the larva, after it is ready to enter its quiescent stage, can not live exposed to the atmosphere. For the experiment in

Table V, 122 eggs were marked on the trees. Thirty eggs died before hatching or were infertile. The remaining 92 hatched and 16 larvæ disappeared and 3 died before molting. Thus 73 larvæ cast their first skin under observation. Of these, 6 disappeared and 2 died before casting the second skin. Thus 65 larvæ molted a second skin under observation. Of these, 5 disappeared and 5 died (1 being destroyed by a coccinellid larva) before shedding the third skin. Of the 55 larvæ which cast the third skin, 8 subsequently disappeared before they were ready to drop to the ground. The larvæ under observation were taken into the laboratory insectary after their third molt, but were not inclosed in cages, so that those which desired to move away could do so. On the trees most of the larvæ which disappeared were dislodged during the operation of molting.

TABLE VI.—*Summary of Table V.*

Instar.	Maximum.	Minimum.	Average.
	Days.	*Days.*	*Days.*
1	8	3	5.3
2	7	2	3.4
3	7	2	4.2
4	10	4	6.6
Total larval period on trees	23	16	18.4

The data in Tables V and VI are in striking contrast to those recorded from San Jose (Table IV), in which the average period spent by the larvæ in vials was 31.6 days. It would appear that the San Jose individuals were retarded by reason of the abnormal character of their food as a result of the feeding of cut leaves. It might be added that the temperature during the period of larval growth in 1913 at Walnut Creek was higher than the mean average for that time of year, and toward the end of April great daily fluctuations occurred; for instance, on April 24 and on May 3 there was a range of 48° F.

Tables VII and VIII give the larval life history at Wenatchee, Wash., in 1915.

TABLE VII.—*Larval life history of the pear leaf-worm at Wenatchee, Wash., 1915.*

No.	Date of—					Length in days.			
	Hatching.	1st molt.	2d molt.	3d molt.	Cocoon.	1	2	3	4
1	Apr. 16	Apr. 23				7			
2	Apr. 18	Apr. 25	May 2			7	7		
3	...do....	...do....	Apr. 29	May 7	May 14	7	4	8	7
4	Apr. 19	...do....	Apr. 28	May 6		6	3	8	
5	...do....	Apr. 26	Apr. 30			7	4		
6	...do....	...do....	May 1			7	5		
7	...do....	...do....	...do....			7	5		
8	...do....	...do....	May 4			7	8		
9	...do....	...do....				7			
10	...do....	...do....				7			
11	...do....	...do....				7			
12	Apr. 21	...do....	May 2			5	6		
13	...do....	...do....	May 3			5	7		
14	...do....	...do....				5			
15	...do....	Apr. 27	May 5			6	8		
16	...do....	...do....				6			
17	Apr. 22	Apr. 28	May 5			6	7		
18	Apr. 23	...do....	...do....			5	7		
19	...do....	...do....	...do....			5	7		
20	...do....	...do....				5			
21	...do....	Apr. 29				6			
22	...do....	...do....				6			
23	...do....	Apr. 30				7			
24	Apr. 24	Apr. 29				5			
25	...do....	...do....				5			
26			Apr. 29	May 7				8	
27			May 8	May 17				9	
28			May 9	May 15				6	
29			...do....	...do....				6	
30			May 15	May 23				8	
31			...do....	...do....				8	
32			...do....	...do....				8	
33			May 17	May 24				7	
34				Apr. 23	Apr. 29				6
35				May 8	May 18				10
36				May 12	May 21				9
37				...do....	May 22				10

TABLE VIII.—*Summary of Table VII.*

Instar.	Maximum.	Minimum.	Average.
	Days.	*Days.*	*Days.*
1	7	5	6.1
2	8	3	6.0
3	9	6	7.6
4	10	6	8.4
Total			28.1

In ascertaining the larval life history at Wenatchee, it was necessary, owing to the distance of the infested orchard, to rear the larvæ on leaves kept in water in the outdoor rearing shelter. These had to be renewed every 4 or 5 days, and the larvæ transferred to the fresh leaves. It will be noted that there was a high mortality among the larvæ, and this may be attributed to the fact that the larvæ had to be handled more or less, and that they did not always have perfectly fresh food upon which to feed. It is probable, also, that the periods between molts were lengthened by this abnormal method of rearing, although observations in the field indicate that the figures for the total larval life are approximately correct. In 1915 most of the larvæ had hatched by April 24, and the largest number were entering the soil about May 20, giving an average larval period of about 26 days. The table shows an average of 28.1 days, and the only larva that was reared to maturity (No. 3) occupied 26 days from egg to cocoon. This is a longer period than at Walnut Creek, Cal. (18.4 days) where the larvæ were reared normally on the trees, and a slightly shorter period than at San Jose (31.6 days), where the larvæ were reared under conditions similar to those in Washington State.

THE COCOON AND PUPA.

In order to determine how deeply the larvæ penetrate the earth for the purpose of spinning their cocoons, 60 full-grown larvæ were placed in a screen cage sunk into the soil and filled with 7 inches of average orchard soil April 30, 1913. By May 3 all the larvæ had burrowed and on June 18 the soil was examined with the results enumerated in Table IX.

TABLE IX.—*Depth in soil for cocooning of the pear leaf-worm, Walnut Creek, Cal., 1913.*

Number of cocoons found.	Inches below soil surface.
46	0 to 1
2	1 to 2
4	2 to 3
1	3 to 4

Fifty-three out of 60 were thus accounted for, and therefore 88.3 per cent of the larvæ spun cocoons. It is evident from Table IX that the great majority spin their cocoons not more than 1 inch below the surface. In the above instance this majority was 86.8 per cent.

Table X shows the depth in the soil at which the cocoons are spun in Washington. On May 21, 1915, 93 larvæ just ready to enter the earth were placed in an open jar on top of 6 inches of fairly closely packed, moist, sandy soil, which is typical of the orchards of the region. In a few days the larvæ had all disappeared and on June 11 the soil was sifted and 71 cocoons were recovered. Thus 76.3 per cent of the larvæ spun cocoons, the others being found dead near the surface. The depths at which the cocoons were found are given in Table X.

TABLE X.—*Depth in soil of cocoons of pear leaf-worm, Wenatchee, Wash., 1915.*

Number of cocoons found.	Inches below surface.
39	0 to ½
24	½ to 1
7	1 to 2
1	2 to 3

Thus 88.7 per cent of all the cocoons were formed less than 1 inch below the surface of the soil. This approximates the percentages found at this depth in California.

Tables XI, XII, and XIII indicate the period spent in the cocoon in California:

TABLE XI.—*Cocoon records of the pear leaf-worm, 1911–12.*

Place.	Date of spinning cocoon.	Date of adult emergence.
San Jose, Cal.	May 13, 1911	Mar. 25, 1912
Do.	May 16, 1911	Mar. 18, 1912
Do.	...do...	Do.
Red Bluff, Cal.	Apr. 25, 1911	Mar. 4, 1912
Do.	Apr. 26, 1911	Mar. 10, 1912
Do.	...do...	Do.

TABLE XII.—*Cocoon records of the pear leaf-worm, 1912–13.*

Place.	Date of spinning cocoon.	Date of adult emergence.
San Jose, Cal.	May 9, 1912	Mar. 23, 1913
	May 10, 1912	Mar. 30, 1913
	May 11, 1912	Mar. 28, 1913
	...do...	Mar. 8, 1913
	May 12, 1912	Mar. 31, 1913
	May 15, 1912	Mar. 7, 1913

TABLE XIII.—*Cocoon records of the pear leaf-worm, Walnut Creek, Cal., 1913–14.*

Date of spinning cocoon, 1913.	Date of adult emergence, 1914.	Date of spinning cocoon, 1913.	Date of adult emergence, 1914.	Date of spinning cocoon, 1913.	Date of adult emergence, 1914.	Date of spinning cocoon, 1913.	Date of adult emergence, 1914.
May 2	Mar. 18	May 4	Mar. 18	May 7	Mar. 20	May 9	Mar. 20
May 3	Mar. 14	...do...	...do...	May 8	Mar. 19	...do...	Do.
Do.	Mar. 15	...do...	Mar. 19	...do...	Mar. 20	May 12	Do.
Do.	Mar. 18	May 5	Mar. 15	...do...	Mar. 21	...do...	Mar. 25
Do.	Mar. 19	...do...	Mar. 20	...do...	Mar. 29	May 13	Mar. 18
Do.	...do...	May 6	Mar. 18	May 9	Mar. 16	...do...	Mar. 19
Do.	Mar. 20	...do...	Mar. 20	...do...	Mar. 18	May 14	Mar. 31
May 4	Mar. 15	May 7	Mar. 18	...do...	Mar. 19	May 16	Mar. 22
Do.	Mar. 18						

The average time spent underground in a cocoon, first as larva and secondly as pupa, is about 10 months and 10 days. Table XIV summarizes the adult emergence recorded in Table XIII.

TABLE XIV.—*Summary of Table XIII, adult emergence of the pear leaf-worm, 1914.*

Number of adults issuing.	Date.	Number of adults issuing.	Date.
1	Mar. 14	1	Mar. 21
3	Mar. 15	1	Mar. 22
1	Mar. 16	1	Mar. 25
8	Mar. 18	1	Mar. 29
8	Mar. 19	1	Mar. 31
8	Mar. 20		

Another lot of 53 cocoons gave almost similar results, the days on which the greatest numbers issued being March 16 and 17.

In 1913 a number of cocoons were examined March 10, and none of the inmates were pupæ. On March 13 one newly molted pupa was observed. It was entirely pale green, with black eyes, and measured 5 mm. by 1.7 mm. On March 30 this pupa began to turn dusky, and on April 2 the head and thorax were black and the abdomen dusky. This pupa failed to develop, but would have issued as an adult about April 5. On March 28, 1913, a fully formed adult was found inside a cocoon. The pupal stage is passed in from two to three weeks.

THE ADULT.

Table XV indicates the adult emergence in Washington of 200 individuals, and their sex, in the spring of 1915.

TABLE XV.—*Adult emergence of the pear leaf-worm, Wenatchee, Wash., 1915.*

Date.	Males.	Females.	Total for each date.	Date.	Males.	Females.	Total for each date.
Apr. 2	0	4	4	Apr. 9	0	8	8
Apr. 3	0	1	1	Apr. 10	0	17	17
Apr. 4	1	12	13	Apr. 11	0	7	7
Apr. 5	1	25	26	Apr. 12	0	3	3
Apr. 6	0	53	53	Apr. 13	0	1	1
Apr. 7	0	52	52				
Apr. 8	0	15	15	Total.	2	198	200

The average length of life of 7 females confined in jars with pear twigs was 5½ days. Comparing the adult emergence in California in 1914 with that in Washington in 1915, we find that in the former locality the maximum date was March 19, while in the northern locality this date was April 6. The activities of the insect certainly commence earlier in the year in California, and this is to be expected when we consider the seasonal differences in the two localities, for the activities correspond with the period of leafing of the tree.

Both in Washington and in California the females have been observed to outnumber the males greatly. Out of 200 adults reared at Wenatchee, Wash., in 1915, only two were males.

Parthenogenesis occurs in this species, and unfertilized eggs hatch readily, as already has been stated. The larvæ live for some time, some of them until the third instar, but it is not definitely known whether any of them ever live to maturity.

NATURAL CONTROL.

Although the pear leaf-worm is apparently a native species, its natural enemies seem to be few, and inefficient in controlling it. No parasites whatever have been recorded in California. At Wenatchee, Wash., several old cocoons, each with a small round hole near one end, were found in May, 1914, indicating the probable existence of a parasite. In the spring of 1915 the possibility of securing parasites was kept in mind. On April 1 three small parasites were found in one of the rearing jars, evidently coming from a single cocoon that had a small hole in it. The following day the sawflies began emerging, and continued to do so until April 13. At this time there were still over a hundred cocoons in the jars, and these were kept for possible parasites.

On April 24 a small ichneumonid, determined by Mr. S. A. Rohwer, of the Bureau of Entomology, as *Mesoleius* sp., emerged from one of the cocoons through quite a large hole that it had made.

On May 4, 27 specimens of the small parasite previously referred to were found in one of the rearing jars, having come from four different cocoons, and in another jar 15 specimens of the same species had emerged from three cocoons, or an average of 6 parasites for each cocoon. These parasites, evidently chalcidids, have not been determined.

On May 19 a single larger parasite was found, which, upon being submitted to Mr. S. A. Rohwer, proved to be a chrysidid, probably *Cleptes provancheri* Aaron.

Thus it appears that of 308 cocoons, only 10, or a little over 3 per cent, were parasitized. The ravages of the sawfly would not be diminished to any appreciable extent by this degree of parasitism, though there may be years when these parasites are much more numerous. It is interesting to note that practically all of these parasites came out considerably later than the adult sawflies, and at about the time when the largest number of sawfly larvæ were full grown. This indicates that the parasites oviposit on the larvæ, which is probably the case, as it is difficult to understand how they could reach the larvæ after the latter had spun their cocoons in the soil. Since there is but one brood of the host, there would be only a single brood of the parasites if peculiar to this host.

In California larvæ of coccinellid beetles in rare instances have been observed to prey on the larvæ of the pear sawfly. Before the first of May coccinellid larvæ are comparatively scarce, and so it is unlikely that they will ever prove a check upon the pear sawfly.

REMEDIAL MEASURES.

The pear leaf-worm is easily controlled when in the larval stage. A poison spray, such as arsenate of lead, if properly applied, is highly effective (Pl. II, fig. 1), because of the habit possessed by this insect of passing the whole period of this stage of its life upon the same leaf, unless forced to move away by interference, accident, or scarcity of food, mainly due to the location of several larvæ on one leaf and the fact that they consume it before they attain the stage of pupation.

The larva shows no preference for any one part of the leaf. The parenchyma and main or lateral veins—even blister-mite galls, when these happen to be present—are consumed in turn as met with during the continuous circular travel of the larva. A spot of arsenate of lead reached in its path of travel becomes part of its food. The larva does not change its course or eat around it because of a dislike for the taste of the poison.

The larval period occurs at a time when spraying is done for more serious pests of the pear. Spraying specifically for its control would coincide with the first application of spray for the codling moth, when the blossoming period is about over and two-thirds of the petals have fallen. The formula of arsenate-of-lead spray used for the latter is quite as effective for the pear leaf-worm.

CALIFORNIA EXPERIMENTS.

In California, when pear orchards are infested with pear thrips (*Taeniothrips pyri* Daniel), the Government formula of distillate-oil emulsion and nicotine[1] used for the control of the pear thrips larva is usually applied at a time when the pear leaf-worms are about all hatched, and is also effective, as a contact-spray control, for the latter.

Therefore, in pear orchards well taken care of, when spraying for the codling moth has become as much of an indispensable practice as that of plowing and cultivating, the pear leaf-worm has less chance of becoming a pest of economic importance, and its control can be considered as correlative with that of both the codling moth and the pear thrips.

TABLE XVI.—*California spraying experiments indicating degree of efficiency of different formulas against the pear leaf-worm, Apr. 29 and 30, 1913.*

Tree sprayed and spray material used.	Number of pear leaf-worms.				
	Dead.	Alive.	Sick.	Per cent dead.	Per cent alive.
Tree No. 1: Lead arsenate 4 pounds, water 100 gallons	31	1	2	91	3
Tree No. 2: Lead arsenate 4 pounds, fish-oil soap 10 pounds, 40 per cent nicotine sulphate 1/1600, water 100 gallons	50	0	0	100	0
Tree No. 3: Fish-oil soap 10 pounds, 40 per cent nicotine sulphate 1/1600, water 100 gallons	17	15	2	50	44
Tree No. 4: Lead arsenate 4 pounds, fish-oil soap 10 pounds, 40 per cent nicotine sulphate 1/1600, water 100 gallons	46	5	1	88½	9½
Tree No. 5: Lead arsenate 4 pounds, fish-oil soap 10 pounds, water 100 gallons	38	17	2	66½	30
Tree No. 6: Lead arsenate 6 pounds, water 100 gallons	39	1	0	97½	2½
Tree No. 7: Fish-oil soap 10 pounds, 40 per cent nicotine sulphate 1/1600, water 100 gallons	16	14	0	53.3	46.6

[1] Foster, S. W., and Jones, P. R. How to Control the Pear Thrips. U. S. Dept. Agr. Bur. Ent. Circ. 131. 24 p., 15 fig. 1911.

To ascertain how far the control of the pear pests just mentioned could be relied upon to keep the pear leaf-worm in check, control experiments were made in the spring of 1913 in California and in 1915 in the State of Washington, and are shown in Table XVI.

Actual count was made 24 hours after spraying, and the larvæ found on the leaves only were taken into consideration. Leaves with holes eaten in them, but with no larvæ present, were not made part of the record. This spray was applied with pressure, the force of which, when hitting the leaves at close range, more than likely caused larvæ to loosen their hold and fall to the ground. It is also more than probable that some sick larvæ likewise fell before the count was made. At that time leaves were noticed with holes in them smaller than those which would have been produced by larvæ remaining on the leaf until their full development had been attained. The mortality therefore would be greater than is recorded in these tables, and this accounts in a measure for the difference in the results found for the same formula applied in California and in the State of Washington, because in the latter instance the experiment was made under laboratory conditions which would afford opportunity for closer observations and would yield more precise results.

Field conditions prevailed in the California experiments, because common every-day spraying, as ordinarily practiced in orchards for other pests, was the only object in view as a control at the same time for the pear leaf-worm.

In the control table (Table XVI) the experiments with tree No. 3 and tree No. 7, in which a contact spray was used containing fish-oil soap and extract of nicotine, indicate a comparatively small percentage of mortality compared to that in which the material contained in addition arsenate of lead, as in the experiment with tree No. 2. But it must be mentioned that in the case both of tree No. 3 and of tree No. 7, the absence of larvæ on leaves with holes when the count was taken was very conspicuous and the larvæ that survived were all large.

A contact spray, whether with or without the addition of distillate oil, is a mechanical emulsion or mixture, which, to be effective, requires application with greater pressure than does a poison spray. Because of this, the liquid strikes the leaves with enough force to dislodge many of the worms, which drop to the ground, where death ensues, caused by the spray adhering to them.

The addition of fish-oil soap to a mixture of water and nicotine extract increases the efficiency of the spray by imparting to the liquid more penetration and better spreading and adhering properties.

WASHINGTON EXPERIMENTS.

In Washington State, where the pear thrips is not to be considered, lead arsenate would appear to be the only logical insecticide to be used against the pear leaf-worm. It is less expensive than extract of tobacco sprays, and easier to mix than oil sprays; besides, the lead arsenate can serve a double purpose—that of controlling this worm and, at the same time, the codling moth. The first application of lead arsenate for the control of the latter is made when the petals of the pear blossom drop, and at this time the larvæ of the sawfly have reached the second instar. The injury done previous to this is negligible; it is only during the last two instars that the larvæ cause serious injury to the foliage.

Mr. Zimmerman, in whose orchard the worst infestation occurred, used lead arsenate at the rate of 4 pounds to 100 gallons of water against the pear leaf-worm with excellent results, both in 1914 and in 1915. The first year there was a very severe infestation of larvæ and the application was made May 16, at the same time that the first codling-moth spray was applied to apples; this was too late for the pears, as the larvæ already had devoured as much as a third of many of the leaves. However, it saved most of the trees from a severe defoliation, as is shown in Plate II, which pictures a tree of which the left half was sprayed while the right half was left unsprayed, the photograph having been taken on May 21, 5 days after the trees were sprayed. The difference was very marked. No definite count was made, but on the sprayed trees scarcely any living larvæ could be found, while many limp and blackened remains were hanging from the partially eaten leaves. In the unsprayed portion of the tree just mentioned, which served as a check, larvæ were numerous, and large numbers of them were dropping to the ground to spin their cocoons.

In 1915 the infestation was not so severe, owing to the control measures of the year before. The orchard was sprayed on May 6, earlier than in 1914. Lead arsenate was used at the same strength as before, that is, 4 pounds to 100 gallons of water. This application effectually checked the ravages of the larvæ, and the trees suffered very little injury.

In 1915 a small experiment was performed with nicotine sulphate, 40 per cent concentration. Infested twigs were placed in water and sprayed with a hand pump. April 27 a twig with 10 second-instar larvæ was sprayed with the nicotine sulphate at the rate of 1 to 1,200, with the addition of a little fish-oil soap. On April 28 the twig was examined and all the larvæ found dead. The larvæ on a check twig were still alive. On this date a similar twig was sprayed in the same way, except that the nicotine sulphate was diluted to 1 to 2,000. This time the check twig was sprayed with clear water. An examination on April 29 showed that all the larvæ sprayed with nicotine were dead, while those sprayed with water were alive.

Control by cultivation is not successful. The Washington orchard in which the spraying was done was kept well cultivated all summer, the soil being in a finely pulverized condition and a dust mulch being maintained for the conservation of moisture. The orchard had been kept in this condition for several years. The cultivation evidently, as a measure of control, had but little effect on the cocoons in the soil. Many of the cocoons are located too near the trunk of the tree to be susceptible of mechanical injury by the teeth of the cultivator, but aside from this they are tough and resist rough treatment, and moisture seems to be an indifferent agent, as indicated in Table I (p. 7), pertaining to moisture conditions.

SUMMARY.

The pear leaf-worm (*Gymnonychus californicus* Marlatt), so far as is known, is a native of the Pacific coast.

Its original host is probably some one or more wild species of plants related to the pear, such as the service berry (Amelanchier), thorn apple (Crataegus), or mountain ash (Sorbus). As to cultivated plants, its selection of food is restricted to the different varieties of pears.

There is only one generation each year. The adult or parent sawflies issue in March and April, the female sex greatly predominating. Eggs are inserted into the pear leaves, the resultant larvæ or worms feeding upon the foliage for an average period of 3 weeks. The larvæ may be found on the leaves during April and May, and in Washington the season is perhaps 10 days or 2 weeks later than in California. Upon acquiring full growth the larvæ drop to the ground and bury themselves in the topmost inch of soil (a few go as deep as 3 or 4 inches) and weave around themselves a brown, oval, tough cocoon in which the insect remains for slightly over 10 months, at first as larva and later for a period of 2 or 3 weeks as a pupa. At the end of the pupal stage the adult issues from the cocoon and comes forth from the ground, and thus the cycle is completed.

Injury is confined to the foliage of the hosts and is done almost entirely by the larva or worm, the presence of which is readily detected by the characteristic circular holes it eats in the leaves. Generally it is of slight economic importance, but in cases of severe attacks trees have been defoliated and have suffered badly.

What few natural enemies the insect has are quite unable to control it. Artificial remedies are correlative with those used against the codling moth and also against the pear-thrips larva, and these are respectively as follows:

Poison spray.—Four pounds lead arsenate to 100 gallons water.

Contact spray.—Fish-oil soap 4 pounds; water 100 gallons; nicotine sulphate (40 per cent concentrate) 1 to 1,200; also the Government formula of distillate-oil emulsion and sulphate of nicotine.[1]

In cases of ordinary infestation the contact spray such as is used for thrips larvæ or aphids will prove successful in controlling the larva of the pear leaf-worm. When the infestation is severe and promises the defoliation of limbs or whole trees the poison spray should be used. The best time for application is when the largest larvæ are about half grown and when the holes in the leaves are not larger than one-half inch in diameter. At this time nearly all the eggs have hatched.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 439

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WM. A. TAYLOR, Chief

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THE SOY BEAN, WITH SPECIAL REFERENCE TO ITS UTILIZATION FOR OIL, CAKE, AND OTHER PRODUCTS.

By C. V. Piper, *Agrostologist in Charge*, and W. J. Morse, *Scientific Assistant, Forage-Crop Investigations.*

CONTENTS.

	Page.
Introduction	1
Soy beans in Manchuria	2
Soy beans in Japan	4
Soy beans in Europe	6
Soy beans in the United States	7
Methods of oil extraction	9
Soy-bean meal as human food	11
Soy-bean meal as stock feed	13
Soy-bean meal as a fertilizer	14
Uses of soy-bean oil	15
Analyses of important varieties of soy beans	16
Possibility of developing a manufacturing industry with American-grown soy beans	17

INTRODUCTION.

The soy bean, although a plant of ancient cultivation in China, Chosen (Korea), and Japan, has become of special importance in the world's commerce only within recent years. In extent of uses and value it is the most important legume grown in Asiatic countries. In these countries the soy bean is used to a very considerable extent for human food, the beans being prepared in various ways. As the bean contains a valuable oil, large quantities are utilized by first extracting the oil and then using the cake for stock feed and as a fertilizer.

Previous to the Russian-Japanese war, China and Japan were not only the greatest producers but also the greatest consumers of the soy bean and its manufactured products. About 1908 the first large importations of beans were received in Europe and America from Manchurian ports. The beans were utilized by extracting the oil, which was found valuable for various industrial purposes, leaving the bean cake as a stock feed. As the value of the oil and cake came to be recognized, new uses and markets were found, and the trade in soy beans became one of great importance, until now it has assumed

NOTE.—This bulletin is intended for general distribution in the Southern States, where it will be of special interest to farmers and cotton-oil millmen. It will also be of interest to farmers of the Northern and Central States and to manufacturers of soy-bean food products.

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such large proportions that the soy bean has become an important competitor of other oil seeds.

As early as December, 1915, several American cotton-oil mills had turned to the soy bean as a source of oil and meal on account of the scarcity and high price of cottonseed.[1] Other manufacturers are preparing soy-bean products for human food. This utilization of American-grown beans for the manufacture of oil, cake, and other products will undoubtedly greatly stimulate the culture of the crop, which until now has been grown in the United States primarily for forage.

FIG. 1.—A fleet of junks engaged in carrying soy beans to Newchwang, Manchuria, from different points in the interior, taking away bean oil and bean cake to other places. (Photographed by F. N. Meyer.)

SOY BEANS IN MANCHURIA.

The soy bean is grown in nearly all parts of Manchuria where agriculture is conducted except in the extreme north. The beans, together with their products—bean cake and oil—form the chief exports (fig. 1). The soy bean is always relied upon by the Manchurian farmer as a cash crop and constitutes a staple product of Manchurian agriculture.

The conditions under which the soy bean thrives are said to be far more varied in Manchuria than in the United States. It is grown

[1] The average market price of cottonseed in the cotton-producing States during the past three years is shown by the following figures, furnished by the Bureau of Crop Estimates: September 15, 1914, $13.88 per ton; September 15, 1915, $20.98 per ton; September 15, 1916, $41.13 per ton.

successfully in semiarid regions, in valleys subject to floods in the rainy season, and in northern latitudes similar to the Dakotas and Minnesota.

In Manchuria the beans are almost entirely produced by hand methods. The seed is usually planted in April in rows 17 inches apart, the plants about 2 inches apart in the rows. In some districts, however, the beans are planted in 24-inch rows, allowing about 7 plants to the foot. The harvest takes place in September, the plants commonly being pulled before they are quite mature, to avoid shattering the pods. The thrashing of the seed is usually accomplished with a stone roller or by trampling, and the winnowing by throwing the beans against the wind.

The beans are bought by Chinese merchants and stored at railway stations. No grading is attempted, the stored beans being of all varieties and mixed more or less with sand and trash. The exporters buy the beans from these merchants simply by weight, but before shipment the beans are sorted.

As to the yields obtained by the Manchurian farmer, there is considerable variation in the figures given by different authorities. Bean experts estimate the yield from 1,100 to 1,600 pounds to the acre, commercial authorities from 1,600 to 1,800 pounds, and Japanese agricultural experts from 400 to 2,000 pounds. In the best bean-producing districts the average yield is said to be more than 1,800 pounds. No reliable statistics as to the cost of production are available, but according to data secured from bean growers the approximate cost per acre is placed at $4.42.

Previous to the Russian-Japanese war soy beans and their products were exported almost entirely to Asiatic countries, Japan being the principal consumer. During the war the local demand greatly increased the production of the crop throughout Manchuria. After the withdrawal of the troops, however, it became necessary to find new markets for the surplus beans. Trial shipments were made about 1908 by Japanese firms to several English oil mills. The suitability of the seed for oil and cake was quickly recognized, and orders for large consignments were made. The bean trade grew rapidly and extended to other European countries and to America. The exports of beans from Manchurian ports have increased and large quantities of oil and cake are exported annually, as shown in Table I.

The ports of Antung, Dairen, and Newchwang are the principal centers of exports from southern Manchuria. Table I shows the exports of beans, bean cake, and bean oil passing through these ports for the years 1909 to 1913, inclusive. Beans from North Manchuria are exported chiefly through Vladivostok, the export figures for beans for the years 1912 and 1913 amounting to 338,451 tons and

391,410 tons, respectively. Adding these quantities to the exports of South Manchuria gives 654,705 tons for 1912 and 599,278 tons for 1913, which may be taken as representing the total exports of beans from Manchuria for these two years.

TABLE I.—*Exports of soy beans, bean cake, and bean oil from the principal ports of South Manchuria, 1909 to 1913, inclusive.*[1]

Exports and ports.	1909	1910	1911	1912	1913
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*
Soy beans:					
Antung	1,643.4	136.1	4,591.5	3,639.8	5,225.6
Dairen	512,469.0	359,665.3	268,732.4	182,628.6	169,300.8
Newchwang	237,020.6	174,562.7	154,187.3	129,985.1	105,341.8
Total	751,133.0	534,364.1	427,511.2	316,253.5	279,868.2
Bean cake:					
Antung	16,349.6	12,054.0	33,166.5	40,111.1	42,322.2
Dairen	318,825.5	277,423.7	463,546.2	378,722.7	566,135.7
Newchwang	356,499.4	327,098.5	386,599.1	282,877.9	298,364.0
Total	691,674.5	616,576.2	883,311.8	701,711.7	906,821.9
Bean oil:					
Antung	92.7	149.6	365.7	558.4	192.1
Dairen	10,850.3	18,753.2	33,729.7	37,466.7	43,392.3
Newchwang	37,875.2	21,356.2	28,039.1	21,826.2	20,752.9
Total	48,818.2	40,259.0	62,134.5	59,851.3	64,337.3

[1] Compiled from U. S. Dept. Com., Daily Cons. and Trade Rpts., No. 115, p. 922, May 16, 1914. (Hanson, G. C. Manchuria's soya-bean trade.)

SOY BEANS IN JAPAN.

The soy bean is cultivated quite extensively throughout the Empire of Japan and occupies about 3.8 per cent of the total area devoted to the cultivation of rice and other cereals. In many districts it is cultivated not in fields by itself, but in rows along the edges of rice and wheat fields. Although not grown to any considerable extent as a main crop by the Japanese farmer, the average annual production is about 18,000,000 bushels. In quality the beans raised in Japan are said to be superior to those of Manchuria and Chosen and are used exclusively in the manufacture of food products. The imported beans, of which very large quantities are obtained from Manchuria and other Asiatic countries, are used principally in the manufacture of bean cake and oil.

The methods of culture of this crop, though varying slightly in different provinces, are quite similar to those employed in Manchuria. The average yield of soy beans to the acre for the last 10 years is 15.3 bushels. The highest average yield recorded is 21.6 bushels to the acre, while the lowest average yield is 8.48 bushels. Accurate data as to the cost of production are not available, but estimates made by Japanese agricultural experts place it at about $10 per acre exclusive of taxes. The average market price in Japan for home-grown beans is about $1 a bushel, while for imported beans it is about 70 cents a bushel.

The soy bean forms one of the most important articles of food in Japan. It is one of the principal ingredients in the manufacture of shoyu (soy sauce), miso (bean cheese), tofu (bean curd), and natto (steamed beans). The beans are eaten also as a vegetable and in soups; sometimes they are picked green, boiled, and served cold with soy sauce, and sometimes as a salad. A "vegetable milk" is also produced from the soy bean, forming the basis for the manufacture of the different kinds of vegetable cheese. This milk is used fresh, and a form of condensed milk is manufactured from it. All of these foodstuffs are used daily in Japanese homes and for the poorer classes are the principal source of protein. To a limited extent, soy beans are used as a horse or cattle feed, being sometimes boiled and mixed with straw, barley, and bran.

Table II shows the exports of soy beans and bean oil from Japan during 1913 and 1914. Prior to 1914 soy beans were not listed separately.

TABLE II.—*Quantity and value of exports of soy beans and soy-bean oil from Japan to foreign countries, 1913 and 1914.*[1]

Country of destination.	Soy beans.		Soy-bean oil.			
	1914		1913		1914	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Pounds.		*Pounds.*		*Pounds.*	
China	62,820	$1,372	220,155	$11,328	184,104	$10,198
United Kingdom	589	21	214,491	11,570	1,019,854	48,687
France			73,890	3,907		
Germany			66	3	10,979	588
Belgium			69,057	3,405	333,735	16,573
United States	421,011	10,125	658,393	34,386	365,478	19,393
Hawaii	203,560	5,296				
British America	246,175	4,540	56,218	3,234	69,652	3,196
Australia	18,070	475	587,413	30,101	120,240	748
Other countries	20,967	504			274,080	18,542
Total	973,192	22,333	1,879,683	97,934	2,378,122	117,925

[1] Compiled from Annual Return of the Foreign Trade of the Empire of Japan, 1914.

As previously stated, Japan has been a large consumer of soy beans and soy-bean products from Manchuria, the greater part of the beans being used in the manufacture of oil and cake. The imports from Dairen, Manchuria, the principal port through which beans and bean products are exported to Japan, are shown for the years 1911 to 1914, inclusive, in Table III.

TABLE III.—*Quantity of imports of soy beans, soy-bean cake, and soy-bean oil from Dairen, Manchuria, into Japan, 1911 to 1914, inclusive.*[1]

Product.	1911	1912	1913	1914
	Tons.	*Tons.*	*Tons.*	*Tons.*
Soy beans	162,703	103,416	90,651	139,222
Soy-bean cake	357,362	357,752	492,985	447,080
Soy-bean oil	9,340	10,889	3,964	4,107

[1] Compiled from Dairen Wharf Office Returns, 1911–1914.

SOY BEANS IN EUROPE.

The soy bean was first introduced into Europe about 1790 and was grown for a great number of years without attracting any attention as a plant of much economic importance. In 1875 Professor Haberlandt, of Vienna, began an extensive series of experiments with this crop and strongly urged its use as a food plant for man and animals. Although interest was increased in its cultivation during the experiments, the soy bean failed to become of any great importance in Europe. At the present time it is cultivated only to a limited extent in Germany, southern Russia, France, and Italy.

Attempts have been made at various times to introduce the soy bean and its products into European markets in competition with manufactures from other oil seeds. Owing to the inferior quality of the beans and cake received, these efforts were generally unsuccessful. About 1908, the first large trial shipment of beans was made to England. As these were received in much better condition than those of previous shipments, the results obtained were so satisfactory that, in 1909, 412,757 tons, in 1910, 442,669 tons, and in 1911, 321,940 tons were imported by European oil mills.

Nearly all of the first large importations of beans were taken by England, where many of the large oil mills devoted their plants entirely to the crushing of soy beans. At this time impetus was given to the manufacture of soy-bean products by a shortage of cottonseed and linseed in England, so the soy bean found a ready market.

Several English firms manufacturing oil-seed cake conducted a series of tests, successfully demonstrating the utilization of the cake, meal, and oil of the soy bean. The cake or meal was soon recognized as a valuable stock feed in the dairy countries, such as Holland and Denmark, where large quantities of oil-seed products are used. The oil was found useful for many trade purposes. The oil and cake were offered at prices which made soy-bean products strong competitors of cottonseed manufactures.

The utilization of the soy bean as an oil seed extended rapidly to the continental countries, and the importations of beans from Manchuria soon reached enormous proportions. That the soy bean and its products have become fully established on the European market is shown in Table IV.

TABLE IV.—*Quantity and value of imports of soy beans, bean cake, and bean oil by European countries, 1912 to 1914, inclusive.* [1]

Product and country.	1912		1913		1914	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
Soy beans:	*Tons.*		*Tons.*		*Tons.*	
United Kingdom	188,760	$7,630,477	76,452	$3,093,863	71,161	$2,886,759
Germany	96,068	3,974,837	107,504	3,974,838	12,843	480,401
Netherlands	42,373	1,592,690	27,119	1,019,317	19,308	725,721
Russia	695	30,250	267,036	6,461,739	....	....
Belgium	1,625	61,095	6,438	199,684	1,002	37,564
Denmark	412	14,035	4,425	115,975	8,187	357,434
France	....	....	34,318	918,008	....	....
Total	329,933	13,303,384	523,292	15,783,424	112,501	4,487,879
Soy-bean cake:						
Netherlands	23,852	836,269	7,230	250,459	1,235	43,964
Germany	7,080	252,912	3,260	111,015	1,201	41,258
Russia	2,059	72,136	21,969	396,944	195	6,507
Denmark	7,620	252,834	15,490	520,857	4,964	164,332
Sweden	4,051	139,391	2,695	91,714	989	33,394
France	1,952	69,367	400	14,016	230	7,903
Total	46,614	1,622,909	51,044	1,385,005	8,814	297,358
Soy-bean oil:						
Netherlands	4,558	250,422	2,828	154,691	10,015	547,820
Belgium	2,083	278,569	363	45,389	137	16,957
Italy	2,252	356,006	4,642	735,490	5,830	953,403
Sweden	1,116	154,434	578	78,491	313	41,867
Austria	617	99,797	1,314	206,078	1,395	224,565
Germany	10,902	1,450,134	3,090	396,032	2,459	296,966
France	1,693	249,486	83	11,397	208	26,917
Russia	....	....	5,150	508,076	....	....
United Kingdom	....	....	95	11,570	455	48,687
Total	23,221	2,838,848	18,143	2,147,214	20,812	2,157,182

[1] Compiled from Koninkryk der Nederlanden, Statistiek van den in-, uit- en doorvoer; Annual Statement of the Trade of the United Kingdom with Foreign Countries and British Possessions; Statistik des Deutschen Reichs, Auswärtiger Handel.

SOY BEANS IN THE UNITED STATES.

Although the soy bean was mentioned as early as 1804 [1] it is only within recent years that it has become a crop of importance in the United States. At the present time the soy bean is most largely grown for forage. In a few sections, such as eastern North Carolina, however, a very profitable industry has developed from the growing of seed. The large yield of seed, the ease of growing and harvesting the crop, the value of the beans for both human and animal food, and the value of the oil all tend to give this crop a high potential importance and assure its greater agricultural development in America.

The soy bean can be grown successfully on nearly all types of soil and has about the same range of climatic adaptation as varieties of corn. The cotton belt and the southern part of the corn belt are most favorably situated for the production of seed of this crop (fig. 2). The yields of seed to the acre in various sections of the United States range from about 15 bushels in the Northern States to about 40 bushels in the northern half of the cotton belt. The average yield in eastern

[1] Willich, A. F. M. American Encyclopedia, 1st Amer. ed., v. 5, p. 13. Philadelphia, 1804.

North Carolina is about 25 bushels, although many fields produce 35 bushels or more to the acre.

The growing and handling of soy beans are accomplished almost entirely by machinery in this country, the ordinary farm equipment meeting all the requirements of this crop. In large bean-growing districts, special harvesters for gathering the seed in the field are used quite successfully. The cost of production varies from $7.50 to $12 per acre, depending on the methods employed in growing and handling the crop. The market price per bushel of seed for sowing purposes varies in different sections, ranging from $1 in large seed-producing sections of the South to $2 or $3 a bushel in the Central and Middle States.

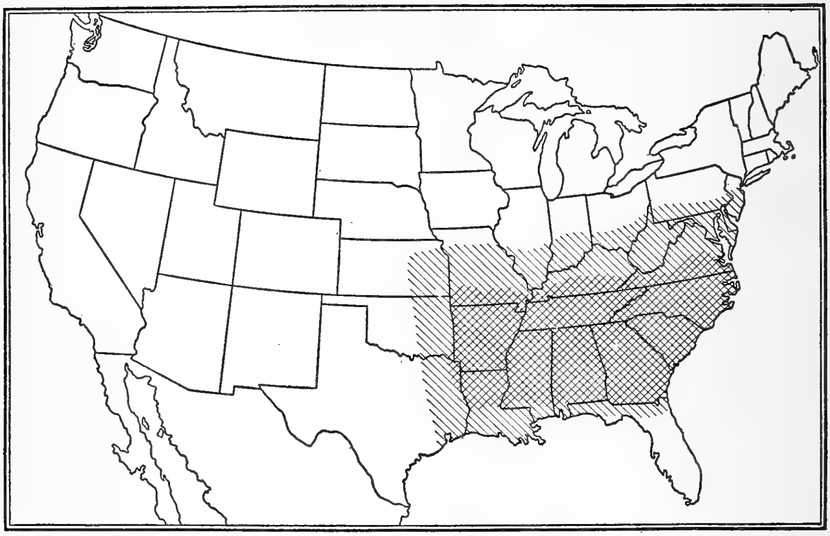

FIG. 2.—Outline map of the United States, showing by double hatching the area to which the soy bean is especially adapted for growing for oil production. The area where the soy bean is less certain of profitable production for oil purposes is shown by single lines.

The first extensive work in the United States with the soy bean as an oil seed was entered upon about 1910 by an oil mill on the Pacific coast. The beans, containing from 15 to 19 per cent of oil, were imported from Manchuria, and the importations, most of which are used in the manufacture of oil and cake, have gradually increased, as shown in Table V. The oil was extracted with hydraulic presses, using the same methods employed with cottonseed and linseed. It found a ready market, as a good demand had been created for this product by soap and paint manufacturers, which up to this time had been supplied by importation from Asiatic countries and England. The soy cake, ground into meal, was placed on the market under a trade name and was soon recognized as a valuable feed by dairymen and poultrymen. The use of the cake has been confined almost wholly to the Western States, owing principally to the high cost of transportation.

During the last few years efforts have been made at various times to interest the cotton-oil mills of the South in the utilization of American-grown soy beans as an oil seed, and experiments were made by a few mills. No extensive work was entered upon until the latter part of 1915. A shortage of cottonseed in the South and a surplus of soy-bean seed in eastern North Carolina led to an increased interest in the possibilities of this crop. Several cotton-oil mills in North Carolina, after preliminary tests, entered upon an extensive production of soy-bean oil and meal. This is the first large manufacture of soy-bean products from American-grown seed. Several cotton-oil mills at the present time are taking an active part in the development of this new industry with American-grown beans. With seed at $1 a bushel and the present prices received for oil and cake, the mills have found it profitable for them to express the oil.

An industry which promises to be of importance in a further utilization of the soy bean is the manufacture of "vegetable milk." At the present time a factory in New York State is being equipped for this purpose. The development of this new enterprise will depend primarily upon the demand created among different industries not only for the milk, but for the flour or meal remaining after the milk is manufactured, which is valuable either as stock feed or for human consumption.

Table V shows the imports of soy beans, bean cake, and bean oil into the United States during the last six years. Prior to 1914 soy beans were not classified separately in the customs returns.

Table V.—*Quantity and value of imports of soy beans, soy-bean cake, and soy-bean oil into the United States, 1910 to 1915, inclusive.*[a]

Year.	Soy beans.		Soy-bean cake.		Soy-bean oil.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Pounds.		*Pounds.*		*Pounds.*	
1910					Not stated.	$1,019,842
1911			[b] 2,115,422	$59,626	41,105,920	2,555,707
1912			[b] 2,416,052	64,350	28,019,560	1,576,968
1913			7,004,803	93,002	12,340,185	635,882
1914	1,929,435	$49,507	3,163,260	38,255	16,360,452	830,790
1915	3,837,865	87,306	5,975,592	64,307	19,206,521	899,819

[a] Compiled from Dept. Com., Bur. For. and Dom. Com. For. Com. and Nav. U. S. 1910–1915.
[b] Includes bean cake, or bean stick, miso, or similar products, with duty, 40 per cent.

METHODS OF OIL EXTRACTION.

The introduction of the soy bean into the Western World for oil purposes has not made any changes necessary in the equipment of the modern oil mills. The methods used in the extraction of oil from the soy bean are similar to those employed with other oil seeds, such as cottonseed and linseed.

In Manchuria the manufacture of oil and oil cake is not confined to large centers, as every small center of bean production has its native mill. The method of extracting oil in these native mills is decidedly primitive. The beans are first crushed beneath a millstone and then steamed for about 15 minutes. The resultant mass is spread out and placed in circular iron frames, about 6 inches deep. Five of these frames are placed one above another in a vertical press, consisting of four uprights, with crossbeams at the top and bottom. Pressure is applied by means of wedges driven in between the cross-

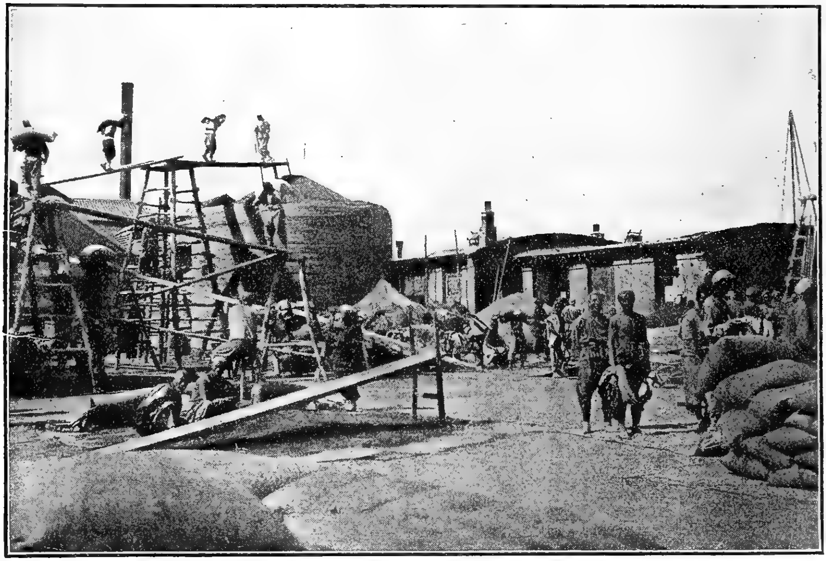

FIG. 3.—Coolies at Newchwang, Manchuria, engaged in carrying loads of soy beans from the junks to big stacks, where they are kept until the factory needs them for oil manufacture. (Photographed by F. N. Meyer.)

beams and beams placed on top of the frames, and the oil is thus expressed. During the last few years large bean mills equipped with modern machinery have been erected, and these are able to extract 3 or 4 per cent more oil (fig. 3). In these large bean mills only about one-half the oil is extracted by the usual process; that is, by crushing the beans, steaming them, and using hydraulic pressure.

A solvent process of extraction, involving the use of benzine, has recently come into use in several English mills, and three such mills are in operation in Manchuria and Japan. The seeds are first finely crushed and then treated directly by the fat solvent. The oil is then taken out of the fat solvent by evaporating the latter, which is distilled and used over again. The residue is well dried and then ground into a fine meal, which is said to contain no detectable trace of the solvent. By this process, nearly all of the oil is extracted, the meal containing only about 1.5 per cent of oil, and 43 to 45 per cent of protein. It is contended that by the solvent process more oil of a better quality is extracted from the beans and the resultant meal is better suited for flour or fertilizer, as it contains less oil. A solvent-process mill recently erected in Manchuria has a maximum capacity of 80 tons of beans every 24 hours. However, only 50 tons of beans were crushed daily, producing 7 tons of oil and 40 tons of meal, the 3 tons which were lost consisting of moisture, dust, and dirt.

In the United States two methods of oil extraction—the hydraulic and the expeller processes—are used by the oil mills. Analyses of cake produced by these methods show about 9 per cent of oil by the hydraulic method and from 4 to 6 per cent by the expeller method. While the cost of producing oil and cake with either process is less with the soy bean than with cottonseed, the cost is much less with the expeller process and a greater amount of oil is extracted. Extensive tests with domestic beans indicate that 1 ton of seed will yield by the expeller process an average of 30 gallons of oil and 1,600 pounds of meal, the difference (about 175 pounds) representing the loss due to cleaning and the evaporation of moisture driven off after the beans have been crushed and heated. The amount of moisture contained in the seeds appears to be a matter of importance in Manchuria, not only for the dealer shipping the beans but also for the mill owner. It has been estimated that 48 pounds of the 1913–14 Manchurian crop yielded 4.7 pounds of oil, while only 4.1 pounds could be expressed from the same quantity of the 1914–15 crop.

SOY-BEAN MEAL AS HUMAN FOOD.

The meal remaining after the oil is extracted from Mammoth soy beans is bright yellow in color when fresh and has a sweet, nutty flavor. The use of the meal as flour for human food has become an important factor in several European countries during the last few years and to some extent in America as a food of low starch content. Soy beans contain at the most but a slight trace of starch, and extensive experiments in America and Europe indicate the value of the bean and its products as the basis of foods for persons requiring a low starch diet.

In England, manufacturers have placed on the market a so-called "soya flour," which is 25 per cent soy-bean meal and 75 per cent wheat flour. This soya flour is being used by bakers in making a soy bread which is very palatable and may be found on the market. A similar product has been manufactured in Amsterdam for 25 years. "Soya biscuits" are also manufactured from this flour and constitute an article of export from England.

German millers have been experimenting to some extent with soy meal in making brown bread by mixing with rye flour. As to the extent to which this bread is now used, no data are available, but it is known that soy meal, on account of the large proportion of protein and phosphates it contains, as well as the palatable products made from it, is gaining in popularity. Soy-bean flour enters largely as a constituent in many of the so-called diabetic breads, biscuits, and crackers manufactured as food specialties.

As a human food, soy-bean flour has been used principally in the United States as a special article of diet and is sold by a number of food companies manufacturing special foods. Extensive tests are being conducted by the United States Department of Agriculture with soy-bean flour in the making of bread.[1] The flour or meal can be successfully used as a constituent for muffins, bread, and biscuits in much the same way as corn meal. In these various food products about one-fourth soy flour and three-fourths wheat flour have been found to be the proper proportions. When a special food of low starch content is desired, as for diabetic persons, a larger proportion of soy flour is used and some form of gluten is substituted for the wheat flour. The addition of the soy flour changes the proportion of protein and carbohydrates in the mixture, as will be noted from the composition of flours shown in Table VI.

TABLE VI.—*Composition of soy-bean flour in comparison with wheat flour, corn meal, rye flour, Graham flour, and whole-wheat flour.*[2]

Kind of flour or meal.	Constituents (per cent).					
	Water.	Ash.	Fat.	Fiber.	Protein.	Carbohydrates.
Soy bean [1]	6.14	5.24	20.71	1.72	39.56	26.63
Soy bean [2]	6.10	6.20	4.50	2.05	47.30	33.85
Wheat	12.00	.45	1.00	.20	11.00	75.35
Corn meal	10.00	.90	2.70	.80	8.50	77.10
Rye	9.00	1.10	1.50	.65	12.00	75.85
Graham	9.60	1.80	2.20	1.90	12.60	71.90
Whole wheat	10.90	1.05	2.00	1.00	12.00	73.05

[1] Flour made from the whole soy bean. [2] Flour made from soy-bean cake.

Although soy-bean milk has been used in both the fresh and the condensed form and in the manufacture of cheese in Japan and China for centuries, it only recently has been considered of possible importance in the United States. Soy-bean milk, owing to its food value and for sanitary reasons, is said to be of the greatest importance for cooking purposes and can be used by bakers, confectioners, and chocolate manufacturers. In Asiatic countries the whole bean is

[1] Attention has been given to the food value of soy beans in connection with studies carried on by the Office of Home Economics. See U. S. Dept. Agr., Farmers' Buls. 58 and 121 and Office Expt. Stas. Bul. 159.

[2] Reported by the Bureau of Chemistry.

utilized in the manufacture of the milk, but quite recently it has been discovered that soy-bean meal, after the oil is extracted, is fully as useful for milk purposes as the whole bean.

If the milk from the soy bean is used in the manufacture of products as a substitute for milk, the labels of such products should indicate that the substitution has been made; otherwise it would constitute adulteration under the food and drugs act.

In addition to its uses for flour and milk, the soy bean can be prepared as human food in numerous ways. The green bean, when from three-fourths to full grown, has been found to compare favorably with the butter or Lima bean. The dried beans may be used in the same way as the field or navy bean in baking or in soups. When prepared in either of these ways the dried beans require a somewhat longer soaking and cooking. The soy bean has been utilized not only in the United States but in European countries as a substitute for the coffee bean. When roasted and prepared, it makes an excellent substitute for coffee. In Asia the dried beans, especially the green-seeded varieties, are soaked in salt water and then roasted, this product being eaten after the manner of roasted peanuts.

SOY-BEAN MEAL AS STOCK FEED.

Soy-bean meal, in addition to its use as a fertilizer, is also used as stock feed. In Manchuria the cake or meal, mixed with bran and kaoliang stalks, is used as feed for horses and mules, but only when very hard work is done. It is also recognized in Japan as a valuable feed for work animals and as a fattening feed for stock not employed in farm work.

In Europe soy-bean cake ground into meal is used almost entirely for feeding cattle, and the low price in comparison with other concentrated feeds has made it very popular. Some hesitation was shown in the dairy countries of Europe when the meal was first introduced, as it was feared that the taste of the butter might be affected by feeding the meal to cows. However, experiments in these countries proved the fear groundless, and the demand for the meal increased steadily. The use of soy-bean meal in America is confined at the present time almost entirely to the Pacific States. It is considered a valuable feed not only by dairymen but also by poultrymen.

Practical experience, supplemented by carefully conducted experiments in the United States and European countries, indicates the high feeding value of soy-bean meal for all kinds of farm stock. The Massachusetts (Hatch) Agricultural Experiment Station conducted a series of tests comparing soy-bean meal with cottonseed meal for feeding dairy cows. It was found that although soy-bean meal imparts a noticeable softness to butter, the cottonseed butter was decidedly inferior in color, flavor, and texture. Doubtless a mixture of these meals in proper proportions would tend to produce a butter of the proper consistency. The value of soy-bean meal for producing meat, milk, and butter is well established. It is one of the cheapest of the highly nitrogenous feeding stuffs and is therefore one of the most economical for balancing rations deficient in nitrogen.

Table VII shows the prices per short ton of soy-bean cake in comparison with other oil cakes which enter largely into the feeding rations of cattle in European countries.

TABLE VII.—*Value per short ton of soy-bean cake and other oil cakes in the principal European countries.*

[From U. S. Department of Commerce, Special Agent Series No. 84.]

Kind of meal.	Germany.	United Kingdom.	Netherlands.	Denmark.	Sweden.
Cottonseed, American	$35.60	$35.85	$39.00	$36.23	$37.05
Soy bean	32.70	....	....	33.80	34.55
Linseed, pressed	32.20	35.84	31.75	33.50	33.40
Peanut, Rufisque	36.60	....	36.10	35.00	35.25

Alleged injurious effects from feeding soy-bean products have been reported to some extent in the United States and Europe, and their cause has been the subject of careful investigation. As yet, however, no proof is to be had of soy beans or their products causing any injurious effects. Owing to its high content of protein, the meal should be used with the same precautions as are observed with other highly concentrated feeds, to avoid digestive troubles.

Table VIII gives analyses of soy-bean meal compared with similar concentrated feeds. As regards digestibility, soy-bean meal compares very favorably with other oil meals.

TABLE VIII.—*Analyses of soy-bean meal and other important oil meals.*[1]

Kind of meal.	Constituents (per cent).					
	Moisture.	Protein.	Fat.	Nitrogen-free extract.	Ash.	Fiber.
Soy bean	7.59	44.65	8.77	27.12	5.89	5.96
Cottonseed	6.62	40.29	7.41	28.63	6.21	10.84
Linseed (old process)	8.98	33.23	7.20	36.51	5.40	8.68
Linseed (new process)	9.63	37.51	2.49	36.09	5.54	8.74
Peanut (decorticated)	10.73	46.84	7.91	24.34	4.89	5.29
Sunflower seed	7.68	23.80	7.94	27.49	5.03	28.06

[1] Average analyses as reported by the Cattle Food and Grain Investigations Laboratory, Bureau of Chemistry.

SOY-BEAN MEAL AS A FERTILIZER.

The utilization of soy-bean meal for fertilizing purposes has been confined almost entirely to Asiatic countries. For centuries bean cake has been sent to the sugar plantations of southern China, and its use gradually spread to the plantations in Java and other tropical islands. The high fertilizing value of the cake has long been recognized by the Japanese, who import large quantities annually for use in the rice fields and as an alternative manure for mulberry trees. In Manchuria large amounts of cake are used annually in soils of low fertility for both field and garden crops.

Although large quantities of soy-bean cake have been imported into the United States during the last few years, there is no mention of its use in the manufacture of commercial fertilizers. With the recent production in the Southern States of bean cake and oil from southern-grown beans, fertilizer manufacturers have become interested in the possibilities of the meal and have purchased considerable quantities for this purpose.

Like cottonseed meal, soy-bean meal contains considerable amounts of phosphoric acid and potash, a large proportion of which is "available," but it is principally valued in fertilizers as a source of nitrogen. If the price is determined on the same basis as that used in calculating the fertilizing value of cottonseed meal, the soy-bean meal is a more valuable product. Its composition with reference to fertilizing constituents and a comparison with cottonseed meal are shown in Table IX.

TABLE IX.—*Fertilizing constituents of soy beans, soy-bean meal, and cottonseed meal.*

Crop or product.	Source of data.	Constituents (per cent).			
		Nitrogen.	Ammonia.	Phosphoric acid.	Potash.
Soy beans	Bureau of Chemistry	6.51	7.90	1.36	1.82
Soy-bean cake	New South Wales Department of Agriculture.	6.77	8.23	1.33	2.00
Soy-bean meal [1]	Elizabeth City Cotton Oil Mills, North Carolina.	7.24	8.79	1.44	1.85
Soy-bean meal [2]	do	7.72	9.37	1.36	1.82
Cottonseed meal	Average of 204 analyses	6.79	8.24	2.88	1.77

[1] From seed grown in 1914. [2] From seed grown in 1915.

While soy-bean meal, as shown in Table IX, has a high value as a fertilizing material, a more economical practice would be to feed the meal to stock and apply the resulting manure to the soil. Feeding experiments indicate that much of the fertilizing value of feeds is recovered in the manure.

USES OF SOY-BEAN OIL.

The oil extracted from the soy bean belongs to the semidrying class of oils; that is, those having properties intermediate between drying oils, such as linseed oil, and nondrying oils, such as olive oil. This oil has a good color, has but a faint odor, and is rather palatable. In many respects it resembles cottonseed oil, but is of a more pronounced drying character. With the rapid growth of the soy-bean industry many new trade uses for the oil have been found, and on account of its lower cost it has become an important competitor of other vegetable oils.

One of the principal uses of the oil in Asiatic countries, chiefly China, is for food, it being consumed largely in the crude state by the poorer classes, but among the rich it is boiled and allowed to stand until clarified. The oil is also utilized in the Orient in the manufacture of foodstuffs, paints, waterproof goods, soap, varnish, and printing ink, and for lubricating and lighting.

Soy-bean oil was at first used in Europe and America in its crude state principally in the manufacture of soft soaps. It is now claimed that some soap manufacturers have a secret process by which the oil can be utilized in the manufacture of the best grades of hard soap. To some extent it is being refined and placed on the European markets as an edible table oil. The refined oil is also used in the manufacture of butter substitutes, and in the Mediterranean countries to blend for salad oil. In the search by manufacturers for new oils to replace linseed oil for paint purposes partly or wholly, soybean oil was found the most suitable. In Europe and the United States, paint grinders are using large quantities of soy-bean oil successfully in the manufacture of certain types of paint. Other trade uses of this oil are the manufacture of linoleum and of a rubber substitute, for which a factory has been established in Germany.

As the process of refining soy-bean oil is improved and perfected there seems to be scarcely any use in which oil has a part in the manufacture of foodstuffs to which it will not be an important adjunct.

Soy-bean oil has been studied with other oils in a series of experiments carried on by the Office of Home Economics and found to compare favorably with the more common culinary table oils with respect to the thoroughness with which it is assimilated.

ANALYSES OF IMPORTANT VARIETIES OF SOY BEANS.

Chemical analyses indicate that considerable variation in composition exists among varieties of soy beans. In determining the range in the oil and protein contents of over 500 varieties grown in the variety tests at Arlington Farm, Va., the percentage of oil was found to range from 11.8 to 22.5 and of protein from 31 to 46.9. The composition of the principal varieties grown in the United States shows a very wide range in the percentage of oil (11.8 to 20.3) and also of protein (34.1 to 46.9) when grown in any one locality. At the present time the Mammoth Yellow variety is most generally grown throughout the South and is the one used in the production of oil. The yellow-seeded varieties, which are most suitable for the production of oil and meal, contain the highest percentage of oil.

Environment has been found to be a potent factor in the percentage of oil in the same variety.[1] Considerable differences occur in oil content when soy beans are grown in different localities. The Haberlandt variety grown in Mississippi, North Carolina, Missouri, Virginia, and Ohio gave the following percentages of oil, respectively: 25.4, 22.8, 19.8, 18.3, and 17.5; while the Mammoth Yellow variety grown in Alabama, South Carolina, Tennessee, North Carolina, and Virginia gave, respectively, 21.2, 19.6, 19.5, 18.4, and 18.8. Variety tests conducted in various parts of the country indicate a higher percentage of oil with the same variety for southern-grown seed. Similar results have been obtained in Manchuria, the North Manchurian beans showing an oil content of 15 to 17 per cent and the South Manchurian beans from 18 to 20 per cent.

The soy bean lends itself readily to improvement by breeding, and experiments indicate the possibility of securing varieties of high oil content by selection. Individual plant selections from a Manchurian variety grown at Arlington Farm, Va., varied from 20.2 to 25.5 per cent in oil content. Analyses of a large number of plant selections from the Mammoth Yellow variety, grown under identical conditions in the same field, showed variations in oil content from 18.1 to 20.4 per cent. It is apparent that there is considerable variation in oil content of the same variety, and an opportunity is offered for developing strains of high oil content. (Table X.)

TABLE X.—*Analyses for protein and oil of important varieties of soy beans grown at Arlington Farm, Va., Newark, Del., and Agricultural College, Miss.*

Variety.	Fat.			Protein.		
	Virginia.[2]	Delaware.[3]	Mississippi.[3]	Virginia.[2]	Delaware.[3]	Mississippi.[4]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Mammoth	18.6		18.6	37.6		41.4
Hollybrook	16.8	16.8	18.5	40.0	40.0	39.0
Manchu	19.2			37.2		
Haberlandt	18.3	18.7		38.5	38.2	
Medium Yellow	19.3	17.6		34.1	40.0	
Ito San	16.6	16.9	17.4	40.3	40.5	39.6
Chiquita	17.6			46.9		
Tokyo	18.4		20.7	35.0		38.1
Lexington	19.1	17.3		34.5	39.1	
Guelph	19.5		20.2	36.8		40.3
Black Eyebrow	17.8			40.8		
Shanghai	18.4		18.5	35.6		41.4
Peking	15.9	17.2	16.4	39.0	36.4	40.1
Wilson	18.4	18.8	17.5	37.8	37.0	39.3
Biloxi			20.3			46.3
Barchet	11.8		15.7	45.9		41.0
Virginia	17.8		17.9	40.2		40.6

[1] Garner, W. W., Allard, H. A., and Foubert, C. L. Oil content of seeds as affected by the nutrition of the plant. *In* Jour. Agr. Research, v. 3, no. 3, p. 227–249. 1914.

[2] Analyses made by Mr. H. A. Piper, Bureau of Chemistry.

[3] Grantham, A. E. Soy beans. Del. Agr. Exp. Sta. Bul. 96. 39 p., illus. 1912.

[4] Robert, J. C. Preliminary report on the economic value of the soy bean, p. 4, tab. 1. Miss. Agr. Coll., 1915.

POSSIBILITY OF DEVELOPING A MANUFACTURING INDUSTRY WITH AMERICAN-GROWN SOY BEANS.

The large annual importations of soy beans, oil, and cake into the United States during the last few years indicate a ready market for products obtained from American-grown beans. The demand for the oil, especially in the manufacture of soap, and its possibilities in the manufacture of paints are very large, and it should be a strong competitor of other vegetable oils, for which the demand is constantly increasing both in this country and in Europe. When the meal becomes properly recognized as a feed material for the production of beef and butter, there will be practically an unlimited market for it as feed. In the dairy countries of Europe, oil meals form a most important part in the stock rations. Denmark feeds more than a tenth of a ton of cottonseed cake (besides other kinds of oil cake) per head of cattle per year. If the cattle in the United States were to be fed at the same rate, the total oil cake or meals of all kinds produced in this country would be insufficient to supply the demand. The numerous experiments being conducted in the preparation of soy-bean products for human food will doubtless result in a much larger use of the meal for this purpose.

It is not expected that the soy-bean industry will develop in the near future to the extent attained in Manchuria. This industry should, however, develop gradually and the soy bean become an important crop in the regions most favorably situated for seed production, especially the cotton belt. Since the boll weevil first entered Texas in 1892, it has been an increasingly important factor in the annual production of cottonseed. At the present time the weevil is found more or less extensively in Texas, Louisiana, Mississippi, Oklahoma, and Alabama and is annually extending its range from 40 to 70 miles. From available statistics it has been estimated that the weevil causes a reduction of at least 50 per cent of the cotton crop in regions invaded by it. As the range of the weevil is gradually extending eastward, where conditions are more favorable for greater damage to the cotton crop, it is readily seen that the quantity of cottonseed available for oil and meal production will be affected to a greater or lesser extent. In Table XI the effect of the boll weevil on the production of cottonseed is plainly shown. The soy bean offers an excellent opportunity to the planter to adjust his plantation management so that he can offset the weevil damage and with profit to himself furnish the cotton-oil mill owners a source of oil and meal.

TABLE XI.—*Acreage, production, and value per ton of cottonseed in the boll-weevil States.*[1]

[The numbers printed in black-faced type indicate the beginning of boll-weevil invasion.]

Year.	United States.			Louisiana.		
	Acres.	Cotton-seed.	Value per ton.	Acres.	Cotton-seed.	Value per ton.
		Tons.			*Tons.*	
1899	24,275,101	4,668,000	$10.28	1,376,254	338,388	$10.29
1902	27,114,103	5,092,000	15.75	1,617,586	422,685	13.50
1903	28,016,893	4,716,000	17.82	1,642,463	395,000	18.74
1904	30,053,739	6,427,000	14.15	**1,745,865**	521,000	13.93
1905	26,117,153	5,060,000	14.89	1,561,774	246,000	15.97
1906	31,374,000	5,913,000	13.76	1,739,000	440,000	12.39
1907	31,311,000	4,952,000	17.64	1,622,000	300,000	16.00
1908	32,444,000	5,904,000	15.65	1,550,000	209,000	16.41
1909	32,044,000	4,462,000	27.96	957,000	112,000	29.28
1910	32,403,000	5,175,000	27.60	975,000	109,000	26.42
1911	36,045,000	6,997,000	18.21	1,075,000	171,000	18.59
1912	34,283,000	6,104,000	21.03	929,000	167,000	22.15
1913	37,089,000	6,305,000	24.84	1,244,000	197,000	20.66
1914	37,406,000	7,186,000	17.93	1,340,000	200,000	18.60

Year.	Mississippi.			Texas.[2]		
	Acres.	Cotton-seed.	Value per ton.	Acres.	Cotton-seed.	Value per ton.
		Tons.			*Tons.*	
1899	2,897,920	634,083	$10.55	6,960,367	1,262,651	$9.82
1902	3,183,989	691,007	14.60	7,640,531	1,198,140	15.00
1903	3,327,960	686,000	18.72	7,801,578	1,185,000	17.95
1904	3,632,458	861,000	15.57	8,355,491	1,507,000	14.32
1905	3,051,265	574,000	15.49	6,945,501	1,219,000	12.75
1906	3,408,000	680,000	12.41	8,894,000	1,858,000	12.50
1907	3,220,000	652,000	15.50	9,156,000	1,024,000	17.35
1908	**3,395,000**	736,000	15.64	9,316,000	1,698,000	13.91
1909	3,400,000	481,000	29.50	9,930,000	1,122,000	26.16
1910	3,317,000	561,000	28.69	10,060,000	1,356,000	24.60
1911	3,340,000	535,000	20.01	10,943,000	1,893,000	17.70
1912	2,889,000	465,000	24.39	11,338,000	2,171,000	18.28
1913	3,067,000	583,000	24.77	12,597,000	1,755,000	23.02
1914	3,100,000	553,000	18.69	12,052,000	2,043,000	15.30

[1] Compiled from U. S. Dept. Com., Bur. Census Bul. 10 (Quantity of cotton ginned in the United States, 1899-1903), 1904; Bul. 111 (Cotton production and statistics of cottonseed products: 1910), 1911; Bul. 131 (Cotton production and distribution, 1914-15), 1915.
[2] The boll weevil entered Texas in 1892.

Although the seed is the factor of prime importance, the improvement to the soil from growing a legume and using the straw as feed should be considered in estimating the value of the crop. In view of the short working season and the fact that no additional equipment is essential in using the soy bean, it seems that the soy-bean oil and meal industry should become an important adjunct of the cotton-oil mills.

The soy-bean industry has gained such importance in Europe that the various countries have been conducting extensive investigations in their African colonies for the production of seed in competition with the Manchurian beans. When soy beans were first imported from Manchuria, the price was about $24 per ton on the European market, but the competition of the European countries for the raw product brought the price quickly to $45 per ton, and during the last three years quotations on the different markets average about $40 per ton.

At these prices it was found that the African colonies were in a favorable position to compete with the bean growers in Manchuria.

Moreover, it is evident that the farmer in America is able to compete on the European and home markets both with the Manchurian and the African bean at the prices prevailing during the last three or four years. Although the cotton-oil mills in the United States estimate that the soy bean can not be worked profitably at a much higher price than $1 per bushel, and then only when the price of cottonseed is higher, available statistics (Table XII) show that the oil mills in Europe have been paying in many instances higher prices for soy beans than for cottonseed.

Although the selling price f. o. b. Manchurian ports ranges from $30 to $35 per ton, the transportation makes the price approximately $40 at American and European ports. If the American grower can raise the beans profitably at $1 per bushel of 60 pounds, the higher yields of seed obtained in this country and planting and harvesting by machinery should enable him to compete on the European market.

Table XII.—*Comparative prices per ton of cottonseed and soy beans on the European market, 1911 to 1914, inclusive.*

Country.	1911		1912		1913		1914	
	Soy beans.	Cottonseed.	Soy beans.	Cottonseed.	Soy beans.	Cottonseed.	Soy beans.	Cottonseed.
United Kingdom	$35.18	$35.86	$40.42	$37.07	$40.47	$36.76	$40.57	$33.63
Germany	37.48	38.78	41.37	39.77	36.97	40.37	37.40	....
Average	36.33	37.32	40.89	38.42	38.72	38.56	....	....

Note.—These figures represent the average price per ton as shown by the importations and valuations of these crops in the Annual Statement of the Trade of the United Kingdom with Foreign Countries and British Possessions and in the Statistik des Deutschen Reichs.

The soy bean is already a crop of high value in American agriculture and seems destined to be of far greater importance, especially in the cotton belt, not only as a cash crop but as an aid in maintaining the fertility of the soil. With a mutual understanding of the possibilities of the soy bean and its products, the industry should become a most important one in conjunction with the cottonseed-oil industry.

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HENRY S. GRAVES, Forester

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LUMBERING IN THE SUGAR AND YELLOW PINE REGION OF CALIFORNIA.

By Swift Berry, *Forest Examiner.*

CONTENTS.

	Page.
Part I. Introduction	1
The region	1
The forest	2
Types of operations	4
Labor	5
Camps	8
Factors affecting the cut	10
Part II. Logging	13
Preparing logs for transport	13
From stump to yard	18
From yard to landing	34
From landing to mill	41
Part II. Logging—Continued.	
Woods supervision	64
Part III. Manufacture	65
Mill pond	65
Sawmills	67
Sawmill lumber yards	80
Transportation to common carriers	86
Part IV. General cost factors	92
Overhead charges	92
Depreciation	95
Summary of the costs of typical operations	96

PART I. INTRODUCTION.

THE REGION.

The sugar and yellow pine region of California extends from the northern boundary of the State southward the entire length of the Sierra Nevada, chiefly west of the summit, and along the Coast Range to Lake County. In this bulletin the region is extended to include the commercial forests of California outside of the coast redwood region, thus taking in the practically pure stands of yellow and Jeffrey pine on the east slope of the Sierras, from the Warner Mountains southward.

The region has three main topographic divisions—the Northern Coast Range, the Sierras, and the east slope of the Sierras and Cascades. The Northern Coast Range begins in Lake County and extends northward along the Trinity and Klamath Mountains to the Siskiyous. This is a region of steep slopes, much broken by secondary ones. The main streams are at low elevations, and the main ridges are narrow but continuous at almost uniform elevations for long distances. The main characteristic of the second division, the Sierras, is deep canyons or stream courses extending in a westerly direction. Between these main streams are high timbered plateaus and ridges. Toward the north the elevations are lower. On the whole the slopes are more uniform and continuous and not so steep as those in the Coast Range. The surface is, however, more often rocky. While the rock of the Coast Range is sedimentary, that of the Sierras is chiefly granite. The third division, east of the Sierras, extends from Truckee on the south to Klamath Lake on the north, and is typically a region of yellow pine timber, fairly easy slopes, and smooth surfaces. There are many broad valleys and level tracts. The soil and rock are volcanic. Although much of this country is actually on the headwaters of streams flowing westward into the Sacramento, it is sufficiently well characterized by the term "East Slope."

The early lumbering operations in California were in the southern part of the East Slope and, on a smaller scale, in the Southern Sierras. At the present time operations are distributed along the entire western border of the Sierras, and a heavy output comes from both the northern and southern ends of the East Slope division. As yet lumbering in the Northern Coast Range is on a small scale, and the timber resources of that region await future development, as do extensive areas of virgin timber lands in the Sierras and on the East Slope.

Because there are no lumbering operations of any size in the Coast Range south of Siskiyou County and none south of the Tehachapis, the scope of this bulletin is practically confined to the Sierras and the East Slope. The descriptions of logging systems and equipment are confined to those actually in use. No attempt is made to contrast methods or efficiency with other regions.

THE FOREST.

The total merchantable stand of saw timber in California, exclusive of the redwood belt, has been estimated at 263,600,000,000 feet, board measure, of which 131,200,000,000 feet is privately owned and 132,400,000,000 feet is the property of the Government. Of the latter amount, 115,800,000,000 feet is in the National Forests and the rest in national parks and Indian reservations or upon the public domain. The private and National Forest timber taken together, a total of 247,000,000,000 feet, board measure, is composed of the principal forest species in about the following proportion: Sugar pine, 15 per cent; western yellow pine, 38 per cent; Douglas fir, 19 per cent; white fir, 14 per cent; incense cedar, 3 per cent; California red fir, 4 per cent; lodgepole pine, 2 per cent; big tree, 2 per cent; other species, 3 per cent.

The region is essentially one of mixed stands. The four typical species are sugar pine (*Pinus lambertiana*), western yellow pine (*Pinus ponderosa*), white fir (*Abies concolor*), and incense cedar (*Libocedrus decurrens*). All four are found throughout the region, though sugar pine and incense cedar are infrequent in the pine stands on the eastern slope of the Sierras. In these stands and at high elevations yellow pine is frequently mixed with or supplanted by Jeffrey pine (*Pinus jeffreyi*). No difference appears to be made commercially between the lumber of these two species, which is known to the trade as white pine or California white pine. Douglas fir (*Pseudotsuga taxifolia*) forms the bulk of the stand in the Northern Coast Ranges; and on the western slope of the Sierras it extends south to Fresno County. In the Northern Coast Ranges this species forms nearly pure stands, but all exploitation of it in California is in connection with other timber species. California red fir (*Abies magnifica*) also forms pure stands, but at such elevations that it is seldom reached by lumbering operations. Lodgepole pine (*Pinus contorta*) is little exploited on account of the inaccessible locations of its stands and of its relatively poor qualities. The stand of big trees (*Sequoia washingtoniana*) timber is confined to the Southern Sierras, where it occurs in large groups or groves. This species is logged, incidentally with other species, for the manufacture of lumber by one large and one small concern.

The stands now merchantable vary in volume from an average of 11,000 feet, board measure, per acre in the pine and white fir stands east of the Sierras to an average of 50,000 feet per acre in the heart of the sugar-pine belt. Other representative stands average 25,000 feet per acre in the Northern Coast Ranges; 23,000 feet on the upper Sacramento; 27,000 feet on the lower Feather River; 25,000 feet on the Consumnes River; 30,000 feet on the Stanislaus River; and 25,000 feet on the Kings River. The maximum stand per acre on record is 200,000 feet, of which approximately 75 per cent is sugar pine. Good quarter sections run as high as 70,000 feet per acre. The majority of the present lumbering operations are located in stands averaging from 18,000 to 40,000 feet per acre.

The timber ranges in size from an average breasthigh diameter of 28 inches to an average of 50 inches for trees over 12 inches in diameter. Individual sugar-pine trees have been found with a breasthigh diameter of 126 inches. The height ranges from 4-log trees in the yellow and Jeffrey pine stands to 13-log trees in the best sugar and yellow pine. A 16-foot length is regarded as the standard log.

The following average figures, which were obtained from the cruising measurements on two large timber sale areas in the Sierras, show the relation between trees over 12 inches in diameter breasthigh of the four leading species, in very good sugar and yellow pine stands:

	Area I.		Area II.	
	Average diameter.	Average number logs.	Average diameter.	Average number logs.
	Inches.		*Inches.*	
Sugar pine	42	9	46	9
Yellow pine	38	8-9	38	8
White fir	33	8	34	8
Incense cedar	31	7	32	6

The average number of 16-foot logs per 1,000 feet, board measure, varies from between three and four in the poor stands to between one and a half and two in the best. The average for the region is between two and three logs per 1,000.

TYPES OF OPERATIONS.

The sawmill plants cutting pine lumber in California range from the small circular mills which produce not more than 200,000 feet per year to one with two large double band mills with a combined annual output of 90,000,000 feet. The small mills, either steam or water power, are supplied with logs by means of horses or oxen, and operate only when there is a local demand for lumber. The large mills run two shifts daily and are furnished with logs by logging railroads and modern steam logging contrivances or big wheels. Between these two extremes are operations of all grades and sizes, the principal intermediate classes being the circular mills producing from 25,000 to 40,000 feet daily for the general market and the single band mills. Most of the large circular mills are supplied by horse logging with trucks or by big wheels or chutes. The single band mills are usually supplied by logging railroads and logging donkeys; a few use horse trucks or traction engines and trucks.

Logging and lumbering operations may be classified according to the size of the mills, because each mill and the logging equipment which supplies it are commonly owned by the same person or corporation. Since none of the mills are located on tidewater, or drivable streams, there are no log markets nor logging companies such as exist in the Pacific Northwest. The 600,000,000 feet of lumber produced in the California pine region annually is manufactured by 15 double-band mills, 14 single-band mills, 25 large circular mills, and a host of small circular mills. Each of these implies a separate lumbering operation, except in the case of one concern operating two double-band mills and another having one single band and one large circular, each with a resaw.

Widely as the operations vary in type, they are alike, with the exception of one new operation, in that logging is done only during the summer months. It may begin during the latter half of April or the first part of May and continue until November or the beginning of December, depending upon the altitude and latitude. The average operation is under way about May 10 and continues until the latter part of November, thus having a season of from 156 to 165 working-days. Sawing begins shortly after the work in the woods and ordinarily continues for from one to four weeks longer. Both logging and milling are customarily shut down for the winter by Christmas or before.

LABOR.

Since most of the labor is employed for less than seven months each year, it is inclined to be unstable. There are two classes—one, to which belong most of the men in the skilled and better-paid positions, winters on the ranches and in the towns of central California, frequently returning to the same operation season after season; the other is purely transient and works on one job from a few days to one season and then moves on to the next. The mill crews are usually much less transient than the woods force.

The labor problem is yearly becoming more difficult, and the proportion of foreign labor is increasing. The bulk of the woods work is now done by American-born workmen. The more tedious work—bucking, swamping, and woodcutting—is largely done by southern Europeans. This is also true of railroad construction, though some companies have Irish and American crews. In some localities Indians perform the cheaper woods work and Mexicans are employed in railroad grading. In the sawmills American labor prevails in the more important positions and in handling machinery. Unskilled labor in the mill and nearly all lumber handlers are southern Europeans. Frequently entire yard crews, with the exception of the foreman, are composed of Italians. Labor in box factories and finishing plants is usually American born and, especially in the box factories, is made up of young men and boys.

Labor for logging camps is usually secured by hiring either at the plant or in the nearest city or large town. In the spring the higher grade employees make application to the superintendent, some even being hired by letter. Many of the other men do the same, but it is frequently necessary for the logging superintendent to visit the nearest city and engage men, paying their way to the works and guaranteeing their unpaid board bills. Later on in the summer, when the men become restless and begin to leave, it is often necessary to secure men from employment agencies, which entails paying the fares to the plant. The men are usually hired by the day or the month. Labor is often employed on contract in felling, limbing, and bucking logs, and in piling lumber. These activities can be easily supervised and require no capital on the part of the contractor. The standard working-day is 10 hours. In sawmills and yards the full time is put in at labor, but in the logging and railroad camps the crews usually return from work on company time, which often means that not over 9¼ or 9½ hours are put in at work. A State law of California provides that boys under 18 years of age can not be worked longer than 8 hours daily.

A workmen's compensation act went into effect in California on January 1, 1914. This act renders the employer liable for compensation for all personal injuries sustained by employees during the course of employment, except in the case of injury due to intoxication or willful misconduct on the part of the employee injured. It provides for the payment of medical and hospital fees for a period of 90 days after injury, for disability indemnities, and for benefits to dependents in case of death, all payments to be made as directed by the Industrial Accident Commission. Another feature of the act is the provision empowering the State Accident Commission to conduct a department for insuring operators against the liabilities. One effect of this act will undoubtedly be an increase in the amount of labor employed on contract.

Medical attention and hospital treatment have been and are yet furnished by most companies at their own hospitals, which are supported by deducting $1 monthly from the wage of each employee. Smaller operators frequently contract with local physicians to care for their men under the same arrangement. The compensation act provides that no deduction may be made in wages to carry out its provisions, but the present hospital charges are apparently made on the basis of care during sickness.

Lumbering wages are paid at a stated sum per day without board or at a stated amount per month and board. The former is customary as far south as Plumas County, and the latter throughout the rest of the region, except at sawmills and yards located in towns. The first system operates in the employer's favor in the case of loss of time through sickness or inclement weather.

In the lists of representative wages for the season of 1913, which follow in Table 1, "North" refers to the territory north of Plumas County, and "Central" to the country south of this point. "East" refers to the region on the east slope of the Sierras about Sierra Valley. The two columns "A" and "B" under each represent different localities or operations.

TABLE 1.—*Wages paid in the sugar and yellow pine lumbering region of California.*

	North (without board).		Central (with board).		East (with board).
	A.	B.	A.	B.	
Railroad work.	*Per day.*	*Per day.*	*Per month.*	*Per month.*	*Per month.*
Grading foreman	$5.00	$4.00	$100.00	$80.00	....
Trestle foreman	4.50				....
Teaming foreman	3.50	....	....	....	....
Powder man	3.00	3.00	45.00	45.00	....
Driller	2.50	2.50	40.00	40.00	....
Teamster	2.50	....	....	40.00	....
Muckers	2.25	2.25	35.00	35.00	....
Section foreman	3.50	3.00	75.00	70.00	....
Section man	2.25	2.25	40.00	35.00	....
Steam logging crew.					
Undercutter	....	....	75.00	....	....
Faller	3.50	3.00	65.00	65.00	$65.00
Bucker	3.00	3.00	50.00	50.00	60.00
Limber	2.75	2.50	50.00	55.00	50.00
Saw filer	4.00	3.50	65.00	....	....
Hook tender	4.50	4.25	100.00	100.00	100.00
Chaser	3.25	....	....	....	....
Frogger	....	2.75	65.00	60.00	70.00
Rigger	2.75	3.00	60.00	50.00	60.00
Swamper	2.75	2.50	60.00	50.00	50.00
Choker-hole digger	2.50	2.50	50.00		50.00
Whistlepunk	2.25	2.25	40.00	....	40.00
Frog shoveler	....	2.25	40.00	40.00	50.00
Lookout	....	....	....	50.00	....
Engineer	3.25	3.25	60.00	65.00	70.00
Fireman	2.75	2.50	40.00	45.00	50.00
Loader	3.25	3.00	60.00	70.00	75.00
Second loader	2.75	2.75	....	50.00	65.00
Winchman	....	....	45.00	....	....
Spool tender	2.75	2.50	....	50.00	50.00
Woodbuck	....	....	40.00	40.00	....
Wood teamster	....	2.50	50.00	....	....
Waterbuck	....	....	45.00	40.00	....
Night watch	....	....	45.00	50.00	....
Chute lineman	....	....	90.00	80.00	90.00
Bellhop	....	....	55.00	50.00	50.00
Chute greaser	....	....	45.00	40.00	40.00
Chute engineer	....	....	80.00	60.00	70.00
Horse-logging crew.					*Per day.*
Wheel teamster	3.25	2.75	....	....	2.75
Bunch teamster	3.25	3.00	....	....	2.50
Hooker	2.75	2.50	....	....	....
Gopher	2.50	2.30	....	....	....
Loader	3.00	2.70	....	....	2.25
Swamper	2.25	2.25	....	....	1.75
Roadman	2.25	2.25	....	....	1.75
Truck teamster	3.75	4.50	....	....	4.00
Skidding teamster	....	3.25	....	....	2.50
Train crew.					
Engineer	5.00	4.00	85.00	....	....
Fireman	3.50	3.00	50.00	....	....
Conductor	4.00	3.75	65.00	....	....
Brakeman	3.10	3.00	50.00	....	....

	Average for region (with board).
Miscellaneous.	*Per month.*
Donkey doctor	$75.00–$80.00
Storekeeper	75.00
Timekeeper	70.00– 85.00
Scaler	60.00– 70.00
Cook	100.00
Second cook	60.00
Cookhouse helpers	45.00

TABLE 1.—*Wages paid in the sugar and yellow pine lumbering region of California*—Con.

Sawmill crews.	Large mills. Per day.	Large mills. Per month.	Small mills. Per day.	Small mills. Per month.
Foreman		$150.00-$175.00		$125.00-150.00
Pondman		50.00- 60.00	$3.00-$3.25	60.00
Scaler	$2.50-$3.00	50.00		
Winchman	2.50	45.00	3.00	60.00
Deckman	2.50- 2.75	45.00- 50.00		45.00
Setter	3.25- 3.50	65.00- 75.00	3.25- 3.75	70.00- 75.00
First dogger	3.25	65.00	2.75- 3.50	45.00- 65.00
Second dogger	3.00	60.00		
Band sawyer	6.00- 7.00		5.00	
Circular sawyer	5.00		4.00- 4.50	
Offbearer	2.50- 3.00	45.00- 60.00	3.00	50.00
Pointer	2.25- 2.75	40.00- 50.00		
Edgerman	3.75	75.00	3.50- 3.75	70.00-75.00
Rear edgerman	2.50	45.00		
Slashman	2.25- 2.50	40.00- 45.00		
Trimmer	3.25		3.00	65.00
Trimmer helper	2.50	45.00	2.50	45.00
Laborer	2.25- 2.50	40.00- 45.00	2.50	45.00
Slabman			2.50	45.00
Cutoff man			2.50- 2.75	45.00- 50.00
Engineer		90.00- 110.00	3.75- 4.75	80.00- 100.00
Fireman	3.00- 3.25	60.00- 65.00	3.25	65.00
Oiler	3.25	65.00		
Millwright	5.00			75.00
Second millwright	3.50			
Filer	7.00- 8.00		3.75- 5.00	
Watchman	2.75	55.00	2.75	50.00
Grader	3.75- 4.00		3.75	
Sorter	2.50		2.50	45.00
Car pusher	2.50		2.50	45.00
Piler	2.50		2.50	45.00

NOTE.—Board is furnished in addition where the wages are monthly; it is not where they are daily.

CAMPS.

TYPES OF CAMPS.

Both the size and location of logging camps depend upon the type of the operation. In most horse logging operations the camps for the loggers are at the sawmill; but in railroad and traction operations they are placed in the woods along the track and as near the logging as possible. To obviate the necessity of long walks to work, large logging camps must be moved at intervals of from one to three seasons. For this reason the portable camp is supplanting the old style permanent type which was torn down or abandoned at every move. The old type consisted of large bunk houses, with double tiers of bunks down the sides. The initial cost of such camps is low, but they can not be moved or kept free from vermin, and the men dislike them.

The portable camp is practically uniform throughout the region. The sleeping quarters are frame cabins 10 by 18 feet or 9 by 22 feet, the former being the usual type on standard gauge operations and the latter on narrow gauge. The sides of these cabins are ordinarily 7 or 7½ feet and the roof half pitch. Low-grade lumber is used in their construction. The walls are battened and the roofs double-boarded or covered with tar paper. Two skid timbers about 8 by 10 inches are placed lengthwise under each cabin to serve as a foundation and to facilitate moving. Cabins of this kind contain about

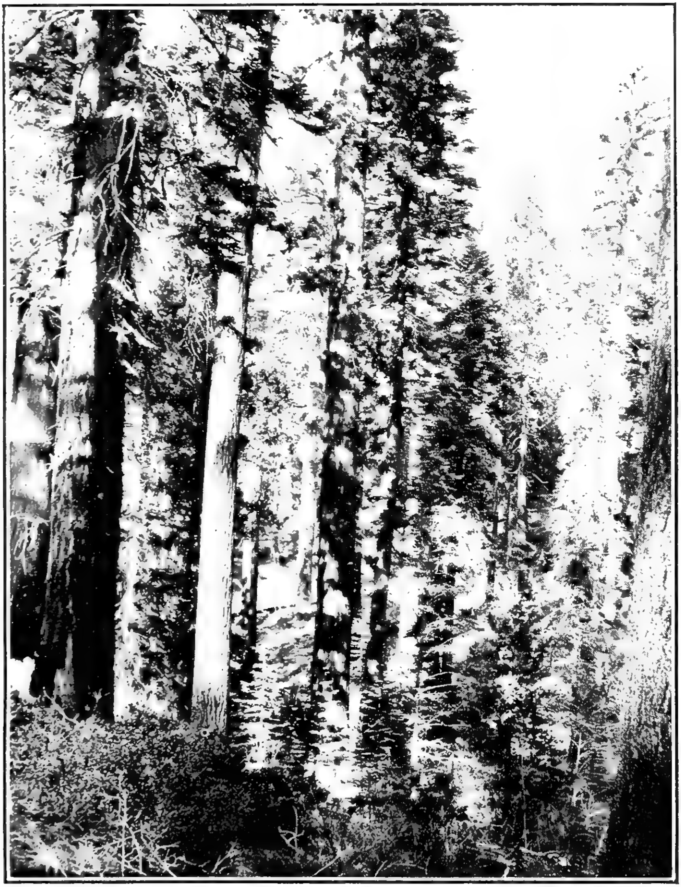

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FIG. 1.—EXCELLENT VIRGIN STAND OF SUGAR AND YELLOW PINE IN THE SIERRA NEVADAS OF CALIFORNIA.

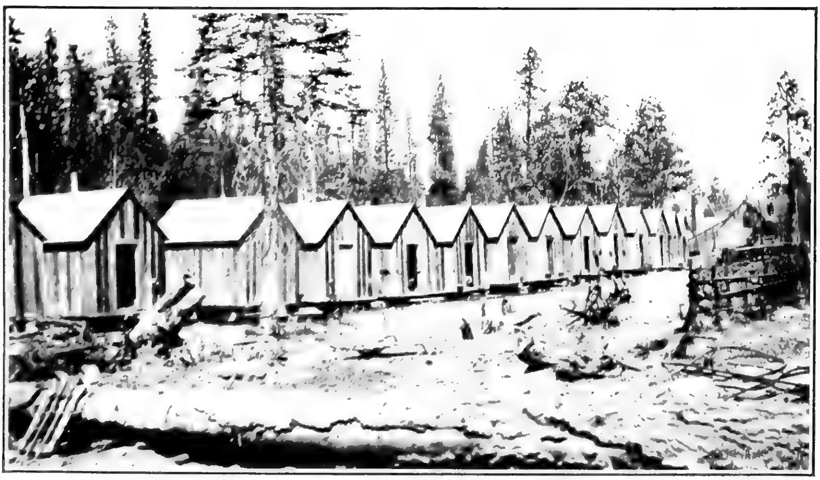

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FIG. 2.—TYPICAL PORTABLE LOGGING CAMP ON A CALIFORNIA PINE DONKEY LOGGING OPERATION.

F—95332

FELLING A LARGE YELLOW PINE TREE IN A MIXED STAND OF SUGAR AND YELLOW PINE ON A NATIONAL FOREST TIMBER SALE AREA.

1,600 feet of lumber and cost from $60 to $70 each. If double-boarded throughout, the cost is probably from $90 to $100. Each accommodates four men in single bunks, or preferably in steel cots, and provides about 500 cubic feet of air space per man. There is also room for a stove and usually a small table. In some camps only three men are assigned to a cabin, which leaves room for a large table. The use of dining cars and bunk cars is limited to a few camps, but will probably increase. For railroad construction camps and camps at a distance from the railroad, and sometimes for stables and dining rooms at portable camps, tents are frequently used. They can be taken down and stored during the winter. If cared for, a good tent should last three or four seasons.

When it is desired to move to a new site, the cabins are loaded on flat cars by means of donkey engines. The cookhouse, stable, and shop are either abandoned or torn down and the lumber utilized again. Ordinarily an average sized camp can be moved in one day. The cabins should last for at least 8 or 10 seasons, depending upon the number of moves. Some operators place several cabins end to end to form a portable cookhouse and dining room.

Steam donkey logging camps vary in size from those with two yarders to those with five. Each large operation usually has at least two camps with two or three yarders each if the logging is good, or four or five yarders each if logging is difficult or if the mill is operating double shift. The first would have from 60 to 80 men and would require about 20 cabins, costing $70 each; a frame cookhouse and dining room 20 by 60 feet, costing $350; one stable, costing $150; and a blacksmith shop, costing $50; making a total cost for buildings of about $1,950. The larger camp would contain from 125 to 150 men and have 45 cabins, a cookhouse costing $450, a stable costing $250, and a blacksmith shop costing $100; total, $3,950.

Bedding is not furnished and mattresses but seldom, though each man is usually permitted to take enough hay for a bed. One company furnishes mattresses, operates a laundry, and provides hot and shower baths in its camps, for all of which each man is charged $2 per month. Small commissaries are provided in most camps and are tended by the foreman and timekeeper.

At small sawmills and mills located in the timber the men are housed in frame cabins larger than those used in the logging camps, though similar in construction. A common dining room is provided, and there may be a few cottages for families. In sawmill towns large boarding houses are usually maintained for the single men and cottages are provided for renting to the married employees.

A modern mill town recently constructed in connection with a double-band mill is reported to have cost as follows:

Mess house	$3,700
Bunk house	2,200
Sewer system	3,400
Water system	3,200
Dwellings	18,000
Total	30,500

BOARDING.

The cost to the company of boarding men usually ranges from $18 to $22 per month, a figure of $20 being the average at mill camps and the one commonly used by most companies in figuring costs. At camps where the employees are required to pay board the rates range from $20 a month to 25 cents per meal, the equivalent of $22.50 per month.

FACTORS AFFECTING THE CUT.

CULL.

Cull is the discount from the gross scale because of rot, breakage, or defects in form. The figures available are based principally upon the judgment of competent timber estimators and scalers, not on actual measurements. Sugar and yellow pine are the least defective and are discounted from 0 to 4 per cent, and sometimes 5 per cent. Douglas fir is quite defective in many parts of the region, particularly in the Coast Range, where the cull ranges from 10 to 25 per cent. White fir has from 10 to 25 per cent cull throughout the region, and red fir stands have about the same amount. Because of its peckiness, incense cedar is the most defective and is culled from 15 to 40 per cent. Measurements covering an area of 360 acres on the Shasta Forest gave the following losses through defects and breakage: Sugar pine, 14.5 per cent; yellow pine, 10 per cent; Douglas fir, 23.5 per cent; white fir, 15 per cent; and incense cedar, 17 per cent.

UTILIZATION.

In the private operations, which make up the bulk of the logging in this region, all of the timber is cut and removed which is considered merchantable by the operator. Stumps are cut from 16 to 36 inches in height, the average for most operations being from 24 to 28 inches. Tops are utilized to limits of from 8 or 10 inches in smooth pine to 14 or 16 inches in rough timber, the average being between 10 and 12 inches for pine and about 12 or 13 inches for fir and cedar. The smallest trees cut are about 14 or 15 inches inside the bark on the stump for pine and 15 or 16 inches for fir and cedar. Some concerns log all trees down to these limits, while others take only the pine and the best and most accessible of the fir and cedar. This difference in policy is usually based on different logging and market conditions. Some operators cut the best white fir trees into logs and the remainder, including tops, into engine wood or pulp wood. An operator whose utilization is of the best type cuts pine down to a 15-inch and fir to a 16-inch diameter on the stump, stumps being cut from 24 to 28 inches high. He cuts smooth pine tops down to 8 inches, smooth fir to 10 inches, and rough tops to 12 and 14 inches. On ordinary logs he allows 4 inches for trimming; and on logs over 4 feet in diameter, 6 inches. He cuts the area clean.

The minimum log length is usually 12 feet, though on several operations valuable pine logs are taken down to 10 feet. Logs of poor quality are left in the woods if 50 per cent defective, and often if only 40 per cent defective; but, on the other hand, many firms log pine butts or clear logs which are not 25 per cent sound.

The utilization on National Forest timber sale areas is commonly more intensive. Timber sale contracts provide that stumps be cut not exceeding 18 inches in height and that tops be utilized down to 8 or 10 inches when smooth. The minimum log length is generally 10 feet, though in some instances 8 feet is specified for sugar and yellow pine. Pine logs $33\frac{1}{3}$ per cent and fir logs 50 per cent sound are considered merchantable. The young growing timber, from 20 to 30 per cent of the volume of the stand above 12 inches in diameter, remains uncut after logging.

In ordinary sawing practice the shortest board made is 10 feet and the narrowest width is 4 inches. However, the mills that have box or door factories resaw slabs to obtain suitable short pieces. Clear edgings are utilized for lath and car strips. Band saws commonly cut two-sixteenth inch or three-sixteenth inch kerf; solid tooth circular saws, four-sixteenth inch; and inserted tooth circular saws, five-sixteenth inch. Most of the clear pine lumber is cut in 1, $1\frac{1}{2}$, and 2 inch stock, and an extra thickness of from one-sixteenth to one-eighth inch is allowed on each board for shrinkage. Shop lumber is $1\frac{1}{2}$ and 2 inches in thickness, the $1\frac{1}{2}$-inch stock being sawed $1\frac{10}{16}$ or $1\frac{11}{16}$ inches thick in coarse-grained timber. Most box lumber is sawed $1\frac{1}{2}$ inches thick, though both 1-inch and 2-inch box is cut. The allowance for shrinkage is the same as in shop. Common lumber is cut in inch stuff, one-eighth inch full. In addition an extra width of from one-eighth to one-half inch is allowed on each board to provide for shrinkage. Fir lumber is usually cut without extra allowance in thickness or width.

OVERRUN.[1]

With average timber and a normal lumber product, the overrun at a mill employing an inserted tooth circular saw is negligible if not lacking. A solid tooth circular saw does a trifle better, showing a possible average overrun of 2 or 3 per cent. The figures obtained at a number of efficient band mills range from 5 to 8 per cent, the most common being 6 per cent or a fraction over. A short mill tally at a band mill sawing pine timber from a National Forest sale in the southern Sierras showed an overrun of 5 per cent.

A mill tally of 4,190 logs made during the summer of 1914 at a representative single band mill in the northern Sierras gave the following average overrun of the decimal C scale: Sugar pine, 7 per cent; yellow pine, 6.9 per cent; Douglas fir, 10.3 per cent; white fir, 2.5 per cent; incense cedar, 15.6 per cent. These percentages are perhaps slightly above the average on account of the manufacture of sawed ties from many top logs. A second tally of 4,890 logs at another single band mill during 1914 gave the following overrun: Sugar pine, 2.6 per cent; yellow pine, 0.7 per cent; Douglas fir, 8.1 per cent; white fir, 1.1 per cent; incense cedar, 16.6 per cent. Most of the overrun occurs in the logs of poorer quality.

TIMBER QUALITY.

The proportion of the various grades produced depends not only upon the quality of the timber but also upon the efficiency of the operation, the size of the mill, and the facilities for marketing lumber. Inefficient operations do not cut as high a proportion of the better grades as efficient ones. Small mills without a marketing organization do not take as much care in separating grades, and frequently put all lower grades into box.

In speaking of the quality of a tract of timber it is customary to say that it will produce a certain per cent of uppers, meaning No. 2 shop and better. The poorer yellow and Jeffrey pine stands in eastern California produce about 20 per cent uppers; better stands produce from 25 to 30 per cent. Normal mixed stands of sugar pine, yellow pine, Douglas fir, white fir, and incense cedar produce from 25 to 31 per cent. In sugar and yellow pine stands the pine commonly cuts from 32 to 45 per cent uppers, yellow pine alone from 30 to 45 per cent, and sugar pine from 35 to 55 per cent.

A comparison of the lumber grades produced from sugar and yellow pine may be made from Table 2, which shows the results of two mill tallies made by the Forest Service during the season of 1914. The first of these was for 2,230 logs at a single-band mill in the southern part of the Shasta National Forest, and the second for 2,490 logs

[1] This information on mill overrun of log scale is derived from a comparison of the figures of scalers and tallymen at several representative mills. The log scale is commonly made by the Spalding rule, which is somewhat similar to the decimal C rule used on National Forest timber sales. Overrun is greater in small or very large logs; less with saws of heavy kerf, and greater when thick planks or timbers are sawed.

F-95331

FIG. 1.—LIMBING AND BUCKING TIMBER ON A NATIONAL FOREST TIMBER SALE IN THE SIERRA NEVADAS.

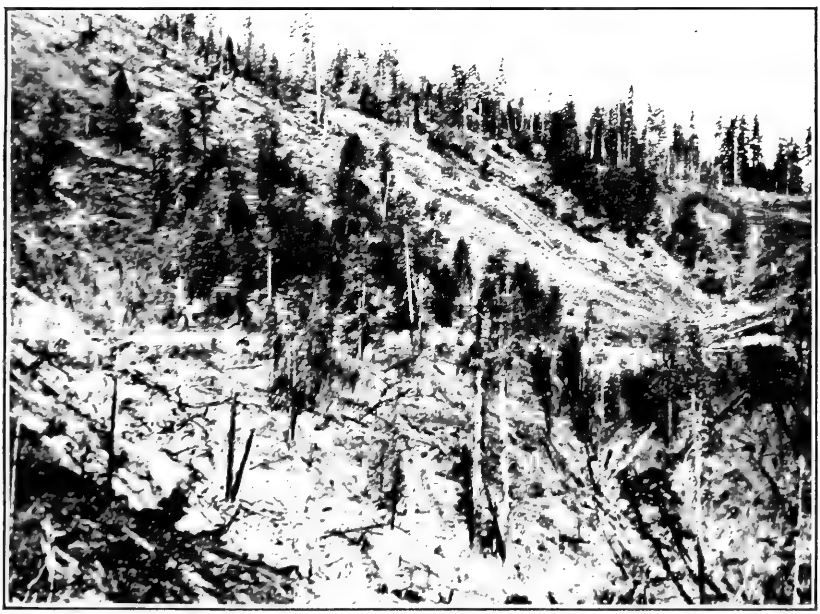

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FIG. 2.—LOGGED-OVER STAND OF SUGAR AND YELLOW PINE ON PRIVATE LAND.

at a single-band mill in the western part of the Plumas National Forest.

TABLE 2.—*Comparison of the lumber grades produced from sugar and yellow pine, showing the results of two mill tallies.*

Grades.	Mill tally No. 1.		Mill tally No. 2.	
	Sugar pine.	Yellow pine.	Sugar pine.	Yellow pine.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Nos. 1 and 2 clear	8.3	8.8	9.4	7.5
No. 3 clear	3.8	4.1	3.3	3.6
C select	.8	.6	.1	.2
Australian	.5	2.4	.2	1.1
No. 1 shop	7.2	8.3	11.9	12.2
No. 2 shop	10.9	13.8	14.2	14.1
No. 3 shop	5.8	4.4	6.2	6.2
Nos. 1 and 2 common	31.3	31.2	41.9	36.5
Box	30.0	25.6	12.5	18.5
No. 3 common	1.4	.8	.2	.1

PART II. LOGGING.

The term "logging" as commonly used covers all the work of handling logs from the standing timber to the sawmill. It is divided, by custom, into several steps. In the discussion which follows, each step is treated separately in the order in which it occurs in logging. The object is to give the various methods of handling each step in such a manner that they may be compared, and, further, to give approximate outputs and costs for different methods under given conditions as an aid in estimating the cost of logging in going or prospective operations.

The cost of delivering logs at the mills in this region, including railroad construction, but exclusive of depreciation on equipment, overhead expenses, and stumpage, range from $4 to $6.25 per 1,000 feet, log scale. Where the railroad hauls are medium and involve an operating expense of not more than $1 per 1,000, the cost in the easy stands is from $4 to $4.75 per 1,000. The cost in most operations is between $4.75 and $5.50 per 1,000. Difficult logging conditions and railroad haul or less efficient methods may raise the cost to from $5.50 to $6.25 per 1,000.

PREPARING LOGS FOR TRANSPORT.

Preparing logs for transport is usually spoken of as felling and bucking, though it includes limbing as well, and sometimes peeling. Felling, limbing, and bucking are commonly considered as a single step. Each felling crew, with the requisite number of limbers and buckers, is a separate unit.

EQUIPMENT.

Each set of "fallers" requires two felling saws, one for use while the other is being filed. The common length is 8 feet, though it is usually necessary to have one or two extra 10-foot saws on the job for the larger trees. Each bucker should have two saws, and there must be some extras in the filing shack. The ordinary length of bucking saws is 7½ feet. Both kinds of saws are commonly 12-gauge on the edge and 17 gauge on the back. The bucking saw has a wider blade than the felling type and may have slightly shorter teeth. The net price at San Francisco of the best quality saws is from 72 cents to 75 cents per foot. Detachable wooden handles are used, which cost about 65 cents per pair for the reversible Pacific coast type and 35 cents per pair for the common type.

Each "faller" carries a felling ax, and each bucker and limber has a swamping ax. All axes are double bit. Felling axes vary in weight from 3½ to 4½ pounds, and the net price is from $9 to $10 per dozen for the best quality. Swamping axes are preferred about one-half pound heavier, and cost 50 cents per dozen more. Handles for these axes cost from $2 to $2.50 per dozen.

For each set of fallers and each bucker there is provided a steel sledge for driving wedges. Those used by fallers weigh from 10 to 12 pounds, and those used by buckers 8 pounds. The cost ranges from 20 to 27 cents per pound. In a well-equipped crew each set of fallers has four steel felling wedges weighing 8 or 10 pounds, and each bucker has three bucking wedges weighing from 4 to 7 pounds. The cost of the best steel wedges is 30 cents per pound.

Often each bucker carries an ordinary shovel. Shovels cost $8 per dozen. The limber or faller marking the log lengths uses an 8-foot marking stick, fashioned from a narrow strip of pine lumber. On steep ground or in large timber each set of fallers commonly has one or two springboards. A bottle of kerosene oil must be carried by each sawyer for the purpose of loosening the pitch which accumulates on the saw. From 1½ to 2 pints daily is required per saw, or from 1 to 1½ gallons for a crew averaging 35,000 feet daily.

A liberal tool allowance for an operation averaging from 110,000 to 120,000 feet daily, all logs bucked into short lengths in the woods, is as follows:

8 felling saws.	48 bucking wedges.
36 bucking saws.	12 felling wedges.
30 axes.	16 shovels.
20 sledges.	4 springboards.

A portable steam drag-saw for bucking at the yarders is listed at $200 f. o. b. Portland, Oreg.

OPERATION.

First the direction in which the tree is to fall is selected and the undercut is made by the undercutter or notcher. The undercutter works ahead and notches each tree with an ax in the direction it should fall, determining the lean of the tree by eye or sometimes using his axe as a plumb line. It is then cut down by the two fallers, who work together with a crosscut saw. In thick-barked timber they usually remove with axes a ring of the outer bark at stump height before sawing. When the set consists of but two fallers, they usually prepare the undercut together, and it may be made entirely with axes or the lower portion may be sawed and the upper chopped. Saws are used for all other felling work, even in small timber. Wedges are used, when necessary, to throw the tree in the direction required.

The limbs are then cut from the merchantable bole. Limbing may follow or precede the marking of the log lengths, which is done by limber, one of the fallers, or, on some jobs, by a log marker. All limbing is done with an ax, and one man to a felling crew is usually sufficient.

Bucking is cutting the bole into logs. It is performed by men working separately, each with a crosscut saw. Wedges are used to prevent pinching of the saw, and a shovel is sometimes necessary when a log lies close to or is embedded in the ground. On some steam and all horse logging operations the logs are bucked into short lengths in the woods; that is, 12, 14, 16, and 18 feet. The more progressive steam loggers are now having the trees bucked in the woods into one, two, and three log lengths. These logs are then bucked into shorter lengths by hand buckers or portable steam saws at each yarder, or by a steam drag saw in the mill pond or on the mill deck.

The standard felling and bucking crew consists of one set of two fallers, one limber, and five buckers. In average timber the average output of such a crew is from 35,000 to 40,000 feet daily. If an undercutter is added, three buckers must also be added, one of whom helps with the limbing. The average daily output of such a crew is about 55,000 or 60,000 feet. Thus, under ordinary conditions each faller is good for from 18,000 to 20,000 feet daily and each bucker for from 8,000 to 9,000 feet.

The daily wages of the smaller crew are from \$23 to \$24 daily, usually the former. Under excellent felling conditions, one more bucker is required, making the daily cost \$25.75; and under severe conditions one less bucker is necessary, thus decreasing the daily cost to \$20.25. On this basis the labor costs of crews of this type are about as follows:

1. Very unfavorable conditions, 26,000 feet daily, 78 cents per 1,000.
2. Poor timber, 30,000 feet daily, 72 cents per 1,000.
3. Fair timber, 35,000 feet daily, 65 cents per 1,000.
4. Ordinary timber, 38,000 feet daily, 60 cents per 1,000.
5. Good timber, 40,000 feet daily, 57 cents per 1,000.
6. Very good timber, 45,000 feet daily, 54 cents per 1,000.
7. Excellent condition, 50,000 feet daily, 51 cents per 1,000.

A labor cost of 60 cents per 1,000 would ordinarily be divided between the different steps of the operation in about the following proportion: Felling, 19 cents; limbing, 7 cents; bucking, 34 cents.

In the very rough timber on the east slope of the Sierras an extra limber is often required at an additional cost of $2.75 per day, or normally 7 cents per 1,000.

The addition of an undercutter and extra buckers increases the output but does not materially affect the cost. The advantage of a very expert undercutter is a saving in breakage. Further, the enlarged crews sometimes fit in better with the size of the logging operations. For example, a small single band mill might be served more cheaply by one set of three fallers than by two sets of two each.

In logging operations where the logs are yarded in long lengths, the standard crew under ordinary conditions is two fallers, one limber, and two buckers. The average daily labor cost of such a crew is $15, which amounts to 50 cents per 1,000 at 30,000 daily; 43 cents per 1,000 at 35,000 daily; 40 cents per 1,000 at 38,000 daily; and 37 cents per 1,000 at 40,000 daily.

Two systems are employed for bucking long logs into short lengths at the yarding engines. The first is used only in the smaller timber of the pure yellow-pine stands, where the work is done by hand. Two men are required at a machine averaging from 25,000 to 30,000 daily and three men at a machine yarding from 38,000 to 40,000. The cost is 23 cents per 1,000 for a machine averaging 26,000 feet per day; 20 cents for one averaging 30,000; 24 cents for one averaging 35,000; and 21 cents for one averaging 40,000. Thus it appears that this system does not reduce the cost of felling and bucking. The saving comes in yarding. In the larger timber a portable steam saw does the bucking at each yarder. Steam is furnished by pipes from the donkey boilers. A 20-foot metallic hose may connect the pipe to the saw in order to permit the saw being moved from one log cut to another. If a hose is not used, each log cut must be spotted at the saw. Two men are required to operate a saw of this type. The daily cost, including upkeep, is about $6. The maximum amount that may be sawed daily is 80,000 feet, or well in excess of the output of any yarder in this region. The cost of sawing is 23 cents per 1,000 at a machine yarding 26,000 daily; 20 cents at one yarding 30,000; 17 cents at one yarding 35,000; and 15 cents at one yarding 40,000. Thus this system lowers the cost of bucking in all cases where the average amount yarded daily per machine is in excess of 30,000 feet.

Many concerns situated in northern California log in lengths up to 32 or 40 feet as far as the mill pond. Logs over 20 feet in length are then bucked once with a steam drag-saw which is located on the pond or just inside the mill. This system saves considerable in bucking and apparently does not increase railroading expenses. The practice of bucking into short lengths at the yarders prevails for chute and most narrow-gauge railroad logging. The method of crosscutting at the mill is becoming more common as the use of chutes decreases and more standard-gauge logging railroads are built.

Felling and bucking is frequently done by contract, usually more cheaply than by day labor. This advantage may, however, be offset by carelessness in felling. Either for this or some other reason most concerns avoid the contract system. The contract rates vary from 15 cents per thousand for felling and 25 cents for bucking on a very favorable operation, the company to furnish and fit tools, to 65 cents per 1,000 for the entire felling and bucking operation under ordinary conditions. Upon one National Forest timber sale area the felling and bucking is contracted for at 75 cents per 1,000.

Peeling the logs is done only in horse logging operations. The larger logs are usually peeled on one side and sniped on the small end. The cost is about one man's time for an operation of from 30,000 to 40,000, or from 7 cents to 10 cents per 1,000. Sniping the ends of the larger logs is also done on some donkey logging operations in heavy timber and loose granitic or volcanic soil. A member of the yarding crew does such sniping in connection with knotting and swamping.

MAINTENANCE.

Saws and axes for felling and bucking, with ordinary use, should last from a half to a full season. The other equipment should last for a season or more. The annual cost of tools and equipment for an ordinary felling and bucking crew is estimated at $250; or 5 cents per 1,000 feet, if the daily output is 35,000. A cheap grade of kerosene is used for the saws, and its cost under any conditions does not exceed one-half cent per 1,000.

One saw filer can easily fit from 10 to 12 saws daily, and 14 by working hard. Fallers use a saw from 1½ to 2 days without refitting, and buckers about 1½ days. Therefore one saw filer can care for the saws of three ordinary sets of fallers or two three-man sets. Thus, ordinarily, there is a saw filer at each camp. The use of steam saws does not make much difference in the amount of saw fitting. The cost of fitting is usually about 4 cents per 1,000, though it may run up to 6 cents.

The cost of maintenance and supplies for felling and bucking is about 8 cents per 1,000 under favorable conditions; 10 cents per 1,000 under normal conditions; and 12 cents per 1,000 under adverse conditions.

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FROM STUMP TO YARD.

After felling and bucking, the logs are collected and taken from where they lie in the woods to a common point from which they are transported to the mill. This common point, or yard, is, in the case of steam logging, at the yarding engine, which may be on a chute, or roading trail, or at a railroad landing. In horse logging the yarding may be terminated at a chute, at a railroad landing, or at a loading point for trucks. In addition to being the first step in log transportation, this is the shortest from the standpoint of distance covered. In the California pine region three methods are in vogue, namely, horse skidding, big-wheel yarding, and donkey yarding. Overhead yarding is becoming established as a fourth.

HORSE SKIDDING.

The simplest method of yarding logs in California is dragging or snaking them along the ground with one or more horses. Especially in the more open yellow and Jeffrey pine stands this method is commonly employed at small mills for delivering the logs to horse chutes or trucks. Ordinarily, no roads or other improvements are necessary, it being simpler to go around obstacles. The logs are always bucked in the woods into short lengths, and usually hauled singly.

Equipment.—The skidding teams range from 2 to 6 horses each, depending upon the distance and the size of the loads. Only heavy work horses costing about $250 each are satisfactory. Such horses average about four or five seasons in the woods; and though some can be sold for a trifle at the end of that period, the annual depreciation is from 20 to 25 per cent, depending upon the severity of conditions. Allowing for 150 working days, the daily depreciation on a horse is estimated at from 38 to 40 cents. To this amount must be added from 75 to 85 cents per day for care and feeding, and about 8 cents for shoeing. A slight additional cost occurs in winter pasturage and in delivery to and from pasture. Thus the average daily cost of horse labor is about $1.40 per horse.

A set of logging harness for two horses costs from $50 to $60. The remaining necessary equipment consists of a pair of spreaders for each span and a heavy draft chain to extend from the log to the leaders. This chain may be passed around one end of the log and fastened with a grabhook, or it may be attached to a short chain fastened to the log with so-called grabs or dogs. In small timber tongs may be used to hitch a single team to the logs. Logs are sometimes fastened together into trails of two by means of a short chain with grabs on either end.

Doubletrees or spreaders cost about $4 per pair, if of wood; and $8 per pair, if of steel. The net cost of horse skidding tongs is about

$4 per pair. Swampers should be outfitted with both a double-bit ax and a crosscut saw.

Operation.—The advisability of horse skidding is determined primarily by the size of the operation and to some extent by the length of the haul. For small circular mills, whose investment must be limited, it proves satisfactory under favorable conditions, such as smooth surfaces, preferably sloping, and timber of moderate size. It is also adapted to slopes (over 20 per cent) too steep for big wheels or trucks. In large operations, areas not suited to big-wheel logging can be yarded more economically by steam contrivances unless the skid haul is very short indeed. A large company located advantageously for a combination of horse snaking and horse chute hauling has during the last few years effected a considerable economy by changing to donkey yarding with increased railroad spur construction. Horse logging on National Forest timber sales is desirable from the standpoint of the silviculturist, because it does less injury to reproduction and uncut trees; but even where it is practicable, the difference in cost is usually so great that it can not reasonably be stipulated in the sale contract. In horse logging the logs may be simply bunched, or they may be hauled as far as 600 feet from either side into chutes or to truck landings. This distance seems usually to be the maximum at which the most effective work is done. Instances are on record, however, where conditions were such that the maximum haul was double this distance. The maximum slope for horse snaking is about 45 per cent.

The simplest form of snaking is rolling and bunching logs together in a position for loading on a truck, when the tract is so gentle in slope that logs may be loaded from practically any point. It is practicable in certain open yellow pine and Jeffrey pine stands. A crew consisting of a swamper and a teamster working with a two-horse team ordinarily furnishes and helps load enough logs for one truck, working on a mile haul. The daily labor and team cost is $9; and with a daily output of 13,000 feet, the average cost is 70 cents per 1,000. In a similar operation on steeper ground, where truck roads are so constructed as to permit the trucks being brought into fairly close proximity to the logs, the average daily output is about 38,000 feet. The crew consists of three swampers and three teamsters with three four-horse teams. The total daily labor and team cost is $36, which is an average of 95 cents per 1,000.

Experience in pine on the eastern slope of the Sierras has shown that in skidding to chutes eight horses, divided into two four-horse teams, working a maximum distance of 600 feet, should put in from 20,000 to 25,000 daily. The crew required is two teamsters and two swampers, and the total daily cost is $26. Thus, under ordinary conditions, the cost should range from $1.05 to $1.30 per 1,000. A concrete example of what may be done under favorable conditions is shown by an operation skidding from 300 to 400 feet into chutes. The daily output is 40,000 feet; and the logs are medium sized sugar and yellow pine, many so large that one side must be peeled. The crew consists of two men sniping and peeling logs, two men swamping, two men with a two-horse rolling team each, and two men with a six-horse skidding team each. The slopes are favorable and the smaller logs are dogged together in trails of two or three. At going wages the cost is about $1.10 per 1,000.

Maintenance.—The principal cost of keeping up a horse skidding operation is depreciation on the horses. The upkeep of tools and other equipment is very light, not in any case more than 4 or 5 cents per 1,000.

BIG-WHEEL YARDING.

Logging to railroad spurs by big wheels is the same operation as is commonly designated in the Lake States and the South as logging with high-wheel carts. Ideal conditions are offered by short hauls, smooth surfaces, absence of underbrush and débris, flat land or gentle slopes, and moderate sized timber. In most of the California pine region the slope is too steep, but the big wheels are used on the east slope and in many places on the west slope of the Sierras. They are used most extensively in the Mount Shasta region.

Ordinarily, no road construction is necessary in big-wheel yarding; but a small amount is required at points where some obstacle makes it necessary to haul to a landing contourwise of the slope or on flats thickly strewn with lava rock, which must be cleared out of the main roads in case of long hauls. The landings are two 6-inch poles placed parallel and at right angles to a loading spur, with a slight excavation between the poles. The construction of one might require the time of one man for one-half day. Slip-tongue big wheels require no landings.

Equipment.—There are two types of big wheels in use. One is the stiff-tongue or Michigan logging wheel. The size used under most conditions has wheels 10 feet in diameter, a 6-foot tread, and 6-inch tires. Where the ground is not too soft a 4-foot log may be straddled. The axle is wooden; and the tongue, which is a small pole fastened rigidly to the axle, is about 16 feet long. The cost is $135 each f. o. b. the factory in Michigan, which would represent about $200 delivered. Twelve-foot wheels, with arched iron axles, designed for large timber, are manufactured locally in California. The cost is about $250 f. o. b. factory. The other style of big wheel is the so-called slip-tongue, designed for steeper ground and longer hauls. The variety in use here has 10-foot wheels, 6-inch tires, a 6½-foot tread, and a 30-foot tongue. The weight fully equipped is 3,600 pounds, and the price, f. o. b. the California factory, is $350.

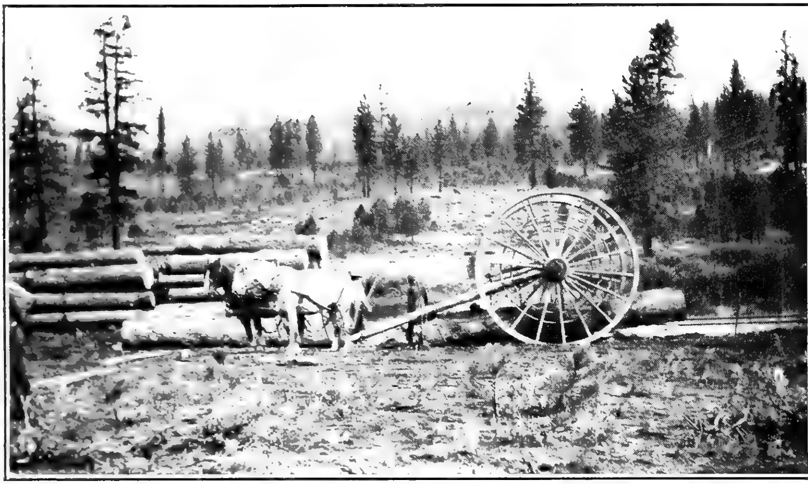

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FIG. 1.—A PAIR OF STIFF-TONGUE BIG WHEELS AT THE LANDING, READY TO UNLOAD.

F-15759-A

FIG. 2.—SLIP TONGUE BIG WHEELS WITH A LOAD OF LOGS, ARRIVING AT A MILL POND.

F-95302

FIG. 1.—YARDING INTO A CHUTE WITH A DOLBEER DONKEY ENGINE. YELLOW PINE STAND IN THE EASTERN SIERRAS.

F-15756-A

FIG. 2.—A 10 BY 11 TANDEM DRUM YARDER WORKING AT A LANDING ON A LOGGING RAILROAD.

The horse and harness equipment is substantially the same as for horse skidding. Each swamper and knotter requires an ax and each gopher an ax and shovel. Each bunching team requires a pair of spreaders, a pair of tongs, and a rolling hook.

Operation.—The operation begins with swamping, which may consist simply of moving the limbs out of the way or may involve cutting a broad road to each tree through thick manzanita and snow-brush. Where there is little or no underbrush, about one swamper is required to each two pairs of wheels, which means in a camp turning out 120,000 daily a crew of four men at a daily labor cost of $10, or 8 cents per 1,000. In thick brush, a foreman and 16 men are required for an operation of the same size. The labor cost is $38.75 daily, or 32 cents per 1,000. Thus, the swamping cost is about as follows: Stands without underbrush, 10 cents per 1,000; stands with heavy underbrush, 20 cents per 1,000; and stands with very heavy underbrush, 30 cents per 1,000. Swamping for slip-tongue big wheels usually costs a trifle more, because more room is required for turning.

After swamping is completed, the logs are bunched; i. e., they are broken apart and dragged or rolled into position for the wheels. This may vary slightly according to the wheel used, because slip-tongue big wheels usually carry bigger loads. Under favorable conditions, two bunch teams supply seven stiff-tongue big wheels, and under ordinary conditions should serve six. With each bunch team is a teamster, a hooker, a gopher, and a knotter. The knotter trims off all limbs remaining on the logs and assists the gopher in making an opening under each load for the binding chain.

Stiff-tongue big wheels are used to advantage on slopes from level up to 12 per cent; and, when it is necessary, may be used on 15 per cent slopes. Work on heavier slopes is not practicable. The maximum hauling distance for efficient work is about one-fourth mile, though sometimes one-half mile and longer hauls are made. Under ordinary conditions one two-horse team is sufficient for each set of wheels. On the out trip the team is hitched on the tongue in the usual manner, and when the load is reached the wheels are backed over it. The tongue is then elevated to a perpendicular position and a binding chain passed underneath the logs and attached to the axle on either side. The team then pulls the tongue to the horizontal, which tightens the binding chain and raises the logs from the ground. The front end of the load of logs and the end of the tongue are then bound together with a lighter chain; the team is hitched short up to the end of the tongue; and the load is ready to proceed.

In small open yellow-pine timber where the slopes are gentle but broken by pitches, two pairs of stiff-tongue big wheels yarding as far as 1,200 feet put in 22,000 daily. The average load consists of about 600 feet, the timber running about four logs to the thousand.

Each set of wheels makes about 19 or 20 trips daily. In addition to a team and driver for each pair of wheels, there are two men and a team to bunch the logs, and a fifth man to dig chain holes under the bunches. The cost of bunching is about $7.10 per day, or 31 cents per 1,000; and of hauling, about $15 per day, or 65 cents per 1,000. The other extreme is found in a stand of timber averaging about two logs per 1,000, where seven pairs of big wheels put in about 120,000 feet daily; maximum haul one-fourth mile. Each pair of wheels has a team and teamster. The remainder of the crew consists of four loaders, one snatch teamster, two roadmen, and one barn man. The bunching is done by two teams and crews. A snatch team is used to help start the heavier loads. The cost of hauling is $60 daily, or 50 cents per 1,000; and the cost of bunching, $26 daily, or 22 cents per 1,000. Under conditions only moderately favorable, the average daily output to be expected would be about 100,000, at a cost of 86 cents per 1,000.

Owing to the weight of the so-called slip-tongues, four horses must be used on each pair. A four-horse team will haul a pair of these wheels up a grade of from 17 to 20 per cent. On heavier grades the wheels must be pulled back over the logs with a cable. When loaded, they will readily come down over pitches of 35 per cent; also a slight adverse grade can be overcome. They can be used on longer hauls; the maximum (where truck hauling becomes cheaper) is reported to be 1½ miles. The reason for these differences in operation lies in the slip-tongue device. The tongue, which slides forward or backward at will, is attached by a long rod to a lever, which is in turn connected with an iron shaft on the top of the axle which tightens or slackens the binding chains. Thus, when the load drags, the tongue is pulled forward and the load raised, which lightens the draft; conversely, when the wheels run ahead, the tongue slides back and the load is allowed to drag and act as a brake.

On a mile haul with fairly good level road about eight round trips are made daily. The average load is about 1,100 feet, making an output of 9,000 daily. The labor cost is $9.50 per day, or $1.06 per 1,000. One bunching team with two men and one swamper is required in the woods for the two wheels. The cost of bunching is about 44 cents per 1,000; and the cost of swamping, 14 cents per 1,000. On a haul of about one-fourth mile a set of slip-tongue high wheels makes 14 trips daily with an average load of 1,200 feet. A team and one man is required for bunching. The cost is about $1 per 1,000 for both hauling and bunching.

Stiff-tongue big wheels are superior for short hauls and good ground. The slip-tongue type is better for long hauls and slopes over 12 per cent. The slip-tongues are sometimes undesirable on timber-sale areas, because of the large amount of swamping required to give room in which to turn them.

Maintenance.—The maintenance of big wheels varies with the size of the camp and the length of the haul. For large camps on one-eighth mile hauls, 5 or 6 cents will cover the tool charge and 10 or 15 cents per 1,000 will meet the repairs. On very long hauls probably 25 cents per 1,000 should be allowed for maintenance.

STEAM-DONKEY YARDING.

The most common method of yarding logs throughout the region is by hauling on the ground with donkey engines and wire ropes or cables. From 75 to 80 per cent of all the timber cut is yarded in this way. This method is variously known as donkey yarding, slack-rope yarding, or steam yarding. It is used by all the larger companies, because it is adapted to a wide range of conditions. Horse logging by large firms is confined to favorable areas, donkey engines being used on all the more difficult ground. Small outfits use horses because of the short life of the operations and the need for limiting the amount invested.

The yarding donkeys are of all types from the light Dolbeer or spool donkey to very heavy and powerful double-drum machines. The principle involved is the same in all: The logs are hauled in from the woods to the machine by means of a wire rope wound on a drum or spool, and the cable is returned to the woods by means of a horse or of a smaller return cable.

The yarders may be set on railroad spurs, at chutes, or on roading trails. In the case of settings on railroad spurs, the yard and landing are identical and that part of the operation termed "from yard to landing" is eliminated. The most efficient loggers are adopting this practice, having found that under practically all conditions it is economy in the end to construct a heavy mileage of logging railroad, thus decreasing yarding distances and eliminating chuting or roading.

Improvements.—Blasting stumps out of yarding trails is usually unnecessary. Only rarely are stumps blasted out and then it is done incidentally by some member of the yarding crew. As the use of large high-speed machines increases, the blasting of stumps may become more common.

Landings of some sort are necessary at practically all donkey settings on loading spurs, except when the donkeys are equipped with A frames. Good landings pay for their construction by eliminating delay in both yarding and loading. On sloping ground they include excavations or frameworks for setting the donkey. The cheapest kind is made by placing two logs parallel at right angles to the track. The type used for loading with a gin pole and cable with end hooks or skids consists of two or three logs at right angles to the track and bumper logs on one or both sides of the track. The cost differs with the amount of clearing and grading necessary. The average is from one-half to one day's work for a yarding crew, or from $20 to $40 each, or say, 2 cents per 1,000. In the open stands of yellow pine a combined bucking chute and landing is used. The landing consists of three logs and a bumper log, and the chute is about 250 feet in length. The average cost is $100, or about 7 cents per 1,000. The most expensive type of landing is that used in a long logging operation on very steep ground. A large excavation must be made in the upper bank of a railroad cut, and bucking chutes 250 feet long are built out in two directions. The average cost is about $300 each, or approximately 8 cents per 1,000.

Equipment.—Donkeys are ordinarily classified by the size of the cylinders, the diameter being given first. The original yarding donkey was the Dolbeer or spool type, which is now used mainly for chute and trestle construction. The standard size Dolbeer has a single 6 by 12 inch cylinder and weighs about 8,000 pounds. The boiler is 36 by 6 inches and carries 160 pounds of steam. It is manufactured in San Francisco and the cost f. o. b. factory is about $1,000. This type has a spool for the yarding line and may have a single drum for the back line. The usual maximum yarding distance is 800 or 1,000 feet.

Practically all the other machines used are return line. All of the engines have two cylinders and are connected by gears to the shafts of two drums, one for the yarding line and one for the back line. These gears may be either direct or compound. Compound gears give greater speed. The drums, placed either tandem or opposite, rotate upon their shafts and are held fast when pulling by means of frictions, which are applied by hand levers. The newer and larger yarding engines have steam frictions on the main drum. A spool or small friction drum may be attached to the shaft of the main drum for loading purposes.

The boilers are upright, ranging in size from 48 inches in diameter and 118 inches in height to 72 inches in diameter and 144 inches in height. Some of the newer types have so-called extension fire boxes which give larger firing space. The boilers of the older types of engines carry about 160 or 165 pounds of steam. The newer types carry from 175 to 200 pounds. It is important in any yarder to have sufficient boiler space to keep up steam pressure, especially in the mornings or after showers, when the fuel is wet.

Small machines, such as 10 by 11 inch tandem drum yarders, and 9¼ by 10 inch and 9 by 10¼ inch compound yarders, are used in the yellow pine stands on the east side of the Sierras. Light, rapid machines which can be readily moved are required because the timber is small and the stand open. Machines of these sizes are usually sup-

F-15946-A

FIG. 1.—A 12 BY 14 YARDER AT A RAILROAD LANDING IN THE SUGAR PINE REGION.

Logs yarded in long lengths and bucked in chute. Separate loading engine below track.

F-16000-A

FIG. 2.—STEAM BUCKING SAW USED FOR BUCKING AT YARDING ENGINE.

F-66706

FIG. 1.—HAULING LOGS IN A TYPICAL HORSE CHUTE IN THE SUGAR PINE REGION.

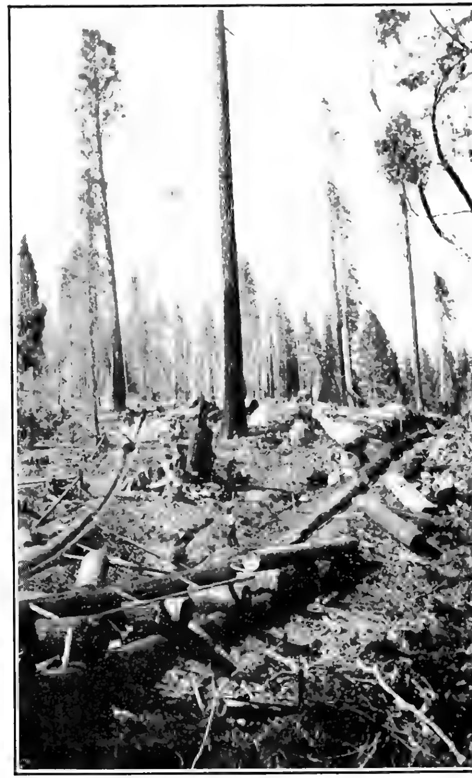

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FIG. 2.—A TRAIL OF LOGS IN A DONKEY CHUTE.

A small yarding engine making up a trail of logs and chute trestle, in the foreground, are shown.

plementary to larger engines. The maximum yarding distance is usually from 1,000 to 1,300 feet. The larger timber, where logging conditions are good, is mostly yarded by slightly larger machines, such as 10 by 12 inch and 10 by 13 inch tandem drum yarders, and 10½ by 10¼ inch and 10 by 11 inch compounds. The maximum yarding distance usually ranges from 1,300 to 1,600 feet.

The machines commonly used for logging in the harder chances in the Sierras, where long hauls and uphill pulls are necessary, are still larger. The smallest are 11 by 13 inch yarders and the largest 12 by 14 inch. The latter are the largest on the market. The maximum yarding distance is usually 2,000 feet, sometimes 2,200 feet. The tendency is to replace worn-out yarders by larger machines, and the manufacturers have accordingly been turning out larger engines each year.

Table 3 gives the approximate prices, f. o. b. factory, for yarding engines.

TABLE 3.—*Prices of yarding engines.*

Size.	Boiler.	Weight.	Cost.
Inches.		*Pounds.*	
10 by 13	60 inches diameter	....	$2,650
8½ by 10	44 inches diameter	15,000	1,750
9¼ by 10	48 by 118 inches	23,000	2,450
	Oblong, 48 inches	25,000	2,600
10 by 11	60 by 126 inches	30,500	2,950
	Oblong, 54 inches	33,500	3,350
11 by 13	66 by 125 inches	37,500	3,500
	Oblong, 60 inches	40,000	3,900
12 by 14	72 by 144 inches	45,000	4,350
	Oblong, 66 inches	50,000	4,800
10 by 11 (tandem)	60 by 126 inches	28,000	2,750
	Oblong, 54 inches	....	3,000
11 by 13	66 by 125 inches	37,000	3,650
	Oblong, 60 inches	....	3,900
9 by 10¼	48 by 106 inches	25,000	2,500
10½ by 10¼	60 by 106 inches	29,500	3,050
11 by 11	66 by 120 inches	35,000	3,500
12 by 12	72 by 120 inches	40,000	4,000
9¼ by 10	48 inches round	22,500	2,400
	54 inches extension	24,500	2,650
10 by 12	54 inches round	29,000	2,850
	54 inches extension	....	3,050
12¼ by 12	68 inches round	43,000	4,000
	68 inches extension	....	4,250

The approximate cost of most yarding engines can be arrived at by allowing 10 cents for each pound of weight.

Freight to California points is about $200 on small engines, $250 on medium, and from $300 to $350 on large engines. In addition each yarder must be equipped with a sled. These range in length from 20 feet for small yarders to 40 feet for large machines. They are usually built by the logger and cost from $200 to $300 each. Either wooden or steel water tanks are built for each machine and placed on the rear of the sleds. The steel tanks give the best service and cost from $100 to $200 each, depending upon the size of the machine. Usually a shelter with a corrugated iron roof is placed on the machines after they arrive in the woods. Three types of efficient spark arresters are in use, varying in price from $12 to $45.

Because of the increase in size of yarding engines, there is a tendency to use heavier wire rope for yarding. At present the most satisfactory sizes for main lines are 1 inch for the small yarders, 1⅛-inch for all ordinary yarders, and 1¼-inch for the larger yarders in rough country with uphill hauls. The universal back line is five-eighths inch, except for very small machines, upon which one-half inch is sometimes used. Dolbeers are commonly equipped with seven-eighths-inch main line and three-eighths-inch back line.

Wire rope for logging is commonly quoted at list prices upon which certain discounts are allowed, varying from time to time with the price of steel. There are two grades, plow steel and extra plow steel. Most logging rope is the latter grade. Yarding rope is commonly composed of 6 strands of 19 wires, each about a hemp center. On account of its greater pliability, rope having 8 strands of 19 wires each is preferred for chokers. Table 4 gives approximate net prices in 1914 per linear foot for standard logging wire rope f. o. b. San Francisco.

TABLE 4.—*Approximate net prices for standard logging wire rope in 1914 at San Francisco.*

Diameter.	Weight per foot.	Plow steel, 6 by 19.	Extra plow steel, 6 by 19.	Extra plow steel, 8 by 19.
Inches.	*Pounds.*	*Per foot.*	*Per foot.*	*Per foot.*
½	....	$0.06	$0.08	....
⅝	0.62	.085	.11	$0.12
¾	.89	.115	.15	.17
⅞	1.20	.15	.19	....
1	1.58	.19	.245	.27
1⅛	2.00	.24	.30	.33
1¼	2.45	.29	.37	.40
1⅜	3.00	....	.44	.48
1½	3.55	.41	.54	.58

Usually four or five chokers are kept on hand at each machine. Each consists of a piece of cable from 15 to 30 feet in length, having a loop on one and a choker hook on the other. They may be made of old yarding cable or new 1-inch 8 by 19 strand.

The proper block equipment for a yarder consists of two "Tommy Moores" or "Jumbos" for the yarding line, and one head or tail block and about six 10 or 12 inch trip-line blocks for the back line. Shackle yarding blocks are still used in a few instances but are rapidly being supplanted by the "Jumbos," since the latter permit the passage of the butt hook and chokers on the outward trip. A moving block is sometimes added to the equipment of a yarder, though usually one of the "Jumbos" is used for moving. Table 5 gives the approximate cost of the best grade of logging blocks f. o. b. San Francisco.

TABLE 5.—*Approximate cost of best grade of logging blocks.*

Kind of block.	Size of sheave.	Weight.	Cost.
	Inches.	*Pounds.*	
Trip line	10 by 1	52	$15
Tail block	15 by $1\frac{1}{4}$	132	25
Do	19 by $1\frac{1}{4}$		35
Yarding block	8 by 2		21
Do	10 by $2\frac{1}{4}$		25
Do	12 by $2\frac{1}{2}$	146	30
Tommy Moore	14 by 8		50
Do	16 by 8		60
Moving block	18 by $2\frac{1}{2}$	230	50
Roading and yarding spool	14 by 8	210	45

In addition to blocks, so-called "fair-leaders" are placed on the front of the sleds of narrow drum yarders, for the main line and sometimes for the back line. The cost ranges from $50 to $100 each, depending upon size.

Operation.—Yarding begins with the moving of the machine to its setting, which may be either on a railroad spur, a chute, or a roading trail. After the machine is set, the back or trip line is hauled out by a horse around several runs, passed through the tailblock and returned to the donkey along the line of the first run. The outer end of the main line is then attached to the back line by means of a clevis. A short piece of cable terminating in the heavy butt hook is fastened to the end of the main line for the purpose of attaching chokers. Since the donkey is usually set parallel to the track or chute, a Tommy Moore is ordinarily placed at a distance of from 200 to 250 feet from the donkey, for a main lead block. Its purpose is to steer the logs into a bucking chute, or to bring them in parallel to the track for loading, and to give the cable the right lead for spooling on the drums. A second Tommy Moore may also be used farther out in the woods when it is necessary to avoid obstacles or change the direction of the lead. The trip line blocks are placed at intervals on the back line to hold it up from logs and rocks.

When the cable has been strung and everything is in readiness for logging, the back line is reeled up on the return drum and the main line hauled out to the first log. A choker has previously been hooked around one end of the log. The free end of the choker is attached to the butt hook and the main line is reeled in, bringing the log with it. The log must be stopped at the lead block, slack pulled in the main line by the back line, and the choker unhooked and passed around the block. At the landing the choker is unhooked and the line returned to the woods for another log.

Each round trip is designated as a turn. The common trail made by the logs taken in from one location of the tail block is called a run. When a run is completed the tail block and back line must be shifted to the next run. One, two, or three logs may be brought in at a turn, depending upon the size of the logs and the power of the machine. One log is by far the most common. The logs may be in single, double, or triple lengths.

The territory yarded from a setting is usually in the form of a more or less complete irregular half circle or half square with the center at the main lead block. The runs extend from this common center in the form of radii. Two settings are often made at the same landing.

The members of the yarding crew are stationed both in the woods and at the machine. The swampers do whatever clearing of limbs and brush is necessary, trim off knots and limbs left on the underside of logs, and snipe large logs when necessary. Either one swamper or a special man, termed variously gopher and choker hole digger, digs holes under one end of each log to allow the passage of the choker. Each swamper is equipped with an ax and the choker hole digger with an ax and shovel. The riggers or rigging slingers put the chokers on the logs and hook on the butt hook. Each yarding donkey is in charge of a logger or hooktender. He usually stations himself along the run where both ends of the operation can be observed. He issues all orders, and plans the arrangement of the lines and the location of the runs. The frogger or blocktender is stationed at the main lead block. He also unhooks and sends back the chokers at the landing. If dirt and débris collect at the frog or landing, they are cleared away by a frog shoveler. A whistle punk stationed in the woods transmits signals by jerking a wire attached to the whistle of the donkey. He also drives the line horse in stringing cable. An engineer and fireman are required at the engine. The men engaged in cutting and packing wood are termed woodbucks. When men are required to pack water on mules or horses they are called waterbucks.

The Dolbeer donkey, when it is used for yarding, is placed on short hauls, about 600 or 800 feet. The logs are invariably yarded in short lengths, though several small logs may be brought in at one time. Several small yarding blocks are used, the principle being to go around obstacles rather than over them. The inhaul is very slow but powerful, and logs can be taken up very steep slopes. When located on a railroad spur, the Dolbeer does its own loading, which necessitates a delay in yarding of about one-half hour for each car. The usual output under these conditions is from 16,000 to 19,000 daily. When yarding is done into a chute, the output is about 15 per cent greater. The standard crew for a Dolbeer consists of 1 logger, 1 engineer, 1 spooltender, 1 lookout, 1 linehorse driver, 3 swampers, and 1 woodbuck. One horse is required for shifting the line. Water is supplied by pumping.

The most efficient donkey logging in the yellow pine and white fir of the East Slope region is done on an operation using 10 by 11 inch and 10 by 13 inch machines, both direct and compound geared. The logging chance is excellent. The stand is well distributed and the timber medium sized, about three logs per 1,000 and five logs per tree. The average stand is from 20,000 to 25,000 per acre. The surface is smooth and the slopes moderate, mostly from 10 to 20 per cent. The railroad is so built that the actual maximum distance is from 1,300 to 1,400 feet. Logs are hauled in long lengths and bucked by hand at the yarders. The amount yarded daily averages from 36,000 to 40,000 for the season. The crew at each machine is composed of 1 hooktender, 2 rigging slingers, 2 swampers, 1 whistlepunk, 1 frogger, 1 frog shoveler, 1 engineer, and 1 fireman. Water is supplied through pipes by pumping and gravity. Slab wood from the sawmill is used for fuel.

Compound machines 10½ by 10¼ inches and 10 by 13 inches are used in the northern portion of the East Slope. The timber here is large, averaging less than two logs per 1,000. The stand is patchy and averages about 20,000 per acre. The surface is smooth but very brushy and the slopes are moderate, averaging about 20 per cent. The logs are cut into both single and double lengths, though mostly into single lengths, because of their large size. The average seasonal output is from 25,000 to 26,000 per day. The approximate maximum yarding distance is 1,400 feet. Each donkey crew is made up of 1 hooktender, 1 head rigging slinger, 2 riggers, 1 choker-hole digger, 1 knotter, 1 whistlepunk, 1 engineer, and 1 fireman. Fuel is supplied by cutting white fir trees into wood, loading this wood on flat cars, and hauling it to each yarder. Water is scarce and is supplied in tank cars. A line mule is used for stringing line.

A typical operation in the sugar and yellow pine of the southern Sierras combines small tandem drum donkeys for hauls up to 1,200 feet and large 11 by 13 inch moguls for distances up to 2,000 feet. The stand averages from 30,000 to 35,000 per acre, and the trees average from six to eight logs. The country is rather rough and the chance of more than average difficulty. The slopes are steep, ranging from 25 to 50 per cent. The plan of logging involves a railroad along the main stream with chutes up the slopes into the timber. The logs are yarded in double lengths and bucked with steam saws. The smaller machines put in from 23,000 to 25,000 feet daily, with the following crew: 1 logger, 2 swampers, 1 rigger, 1 lookout, 1 frogger, 1 frog shoveler, 1 engineer, 1 fireman, and 1 woodbuck. The larger machines average from 28,000 to 30,000 daily, and have the following crew: 1 logger, 1 head rigger, 2 riggers, 2 swampers, 1 whistlepunk, 1 frogger, 1 frog shoveler, 1 engineer, 1 fireman, and 2 woodbucks.

Water is supplied both by pumping and by gravity. A horse is required at each machine for shifting cable when changing runs.

One company in the southern Sierras uses 12 by 14 inch yarders with $1\frac{1}{4}$-inch cable for yarding distances up to 2,000 feet. The country is one of steep slopes on both sides of numerous streams in a common watershed. The logging railroad follows contourwise along these slopes. The machines are set along the railroad, and the logs are yarded to the track, both up and down hill. The slopes above the track range from 25 to 40 per cent, and those below the track from 40 to 70 per cent. The surface is smooth and there is little underbrush. The virgin stand is about 40,000 feet per acre. The logs are yarded in long lengths and bucked at each yarder with a steam saw. The daily output is about 38,000 or 40,000 feet, with the following crew: One hooktender, 1 frogger, 3 riggers, 1 chokerhole digger, 2 frog shovelers, 1 whistlepunk, 1 engineer, 1 fireman, 1 woodcutter, and 1 wood teamster.

The average outputs given in the above examples include a time allowance for moving donkeys, but not the building of frogs or landings. It is usually more economical to have landings built by separate crews than by the yarding crew. In easy country a donkey will make the usual one-fourth or one-third mile move under its own power in one-half day. In rough country double that time is required. The donkeys are frequently moved on flat cars on the logging railroads. From three-fourths to one day is required for such a move, regardless of distance. Moving time is measured from the bringing in of the last log on one setting until the line is out ready for logging on the next. Light donkeys are moved more quickly than heavy ones. The period between moves depends upon the output of the donkey, the stand per acre, and the area of the setting. It usually ranges from three weeks to two months.

The usual time of changing a tailblock from one run to another is from 20 to 30 minutes, depending upon the character of the country. More difficult changes, or changes around several runs, require from 30 to 50 minutes. Eliminating very unfavorable settings, the average time required for a turn is about 15 minutes. On short hauls, it may be as low as six or seven minutes, and on long difficult hauls, as high as 25 minutes. The size and speed of the machine and the character of the timber and topography all affect the time of a turn, but when delays due to loading, bucking, or frogging are considered, the average for most operations is about four turns per hour. The following information regarding the time of logging turns is intended only to give the approximate relation of the various parts of each turn. In a yellow-pine stand under very good conditions a 10 by 11 inch tandem drum yarder hauling 1,200 feet averaged a turn in 13 minutes, divided as follows: Outhaul 3, hooking three-fourths, inhaul $3\frac{1}{4}$, hungup $4\frac{3}{4}$, block one-half, and landing three-fourths minutes. A compound geared machine under the same conditions, yarding from 900 to 1,000 feet, made an average turn in $8\frac{3}{4}$ minutes, as follows: Outhaul $2\frac{1}{4}$, hooking one-half, inhaul $3\frac{1}{4}$, hungup $1\frac{1}{4}$, block one-half, and landing 1 minute. Delays waiting for steam brought the average up to 11 or 12 minutes. A 10 by 12 inch tandem drum machine, yarding from 700 to 800 feet on fair ground in large timber, with two bull blocks, averaged a turn in $13\frac{1}{4}$ minutes, as follows: Outhaul $1\frac{1}{2}$, hooking $1\frac{1}{2}$, inhaul $2\frac{1}{2}$, hungup $4\frac{3}{4}$, first lead block $1\frac{1}{4}$, main lead block three-fourths, and landing 1 minute. A 11 by 13 inch yarder in a fairly rough country averaged 14 minutes to a turn on a down-hill haul of 1,500 feet. A similar machine hauling uphill 800 feet averaged 10 minutes per turn. An addition of 500 feet increased the average time by 10 minutes. Usually the average time required at a lead block is about one-half minute under favorable, three-fourths minute under normal, 1 minute under difficult, and $1\frac{1}{4}$ minutes under very difficult conditions. The time required to change a choker, on a log hungup behind a tree or stump, ordinarily varies from 1 to $1\frac{1}{2}$ minutes.

The type of donkeys selected depends upon the character of the timber and ground. The Dolbeer is apparently going out of use, because labor is too great a factor in its operation and its maximum yarding distance is too short. Small compound machines are preferred in small rather light timber where the maximum yarding distance is short. Medium-sized machines are used in larger timber under similar conditions. Slightly larger engines are adopted in localities where the chance is more difficult and the yarding distance longer. The largest yarders are used where it is desired to haul extra long distances both up and down hill and over all obstacles. Compound geared machines carry less cable than the tandem drum type. The tandem drum machines can also be used as roaders, if occasion demands. As a rule, the smaller yarders, with shorter lines, do more satisfactory work upon National Forest timber sale areas.

Operators are finding it an economy to construct more logging spurs and thus shorten the yarding distance. Hauling logs in double and triple lengths and bucking at the yarder or mill pond greatly increases yarding efficiency, if the work is well arranged. The longer sections decrease the time of hooking in the woods, follow the run better, hang up less, and yield more in scale feet, board measure, per turn. A machine should average 5,000 more daily hauling long logs than short logs. More powerful machines are required, however.

Wood is the universal fuel for yarders. Oil burning is not attempted, because of the difficulty of delivering oil at the machines.

The greater portion of the wood used consists of limbs, especially sugar pine, cut into lengths on the ground. This limb wood may be carried to the yarder by the woodbuck or packed on a mule for small machines. For larger machines, it may be dragged on a sled by either one or two horses, or hauled in a two-horse cart. In a few instances in the northern Sierras sound Douglas fir logs are cut by hand into fuel at the yarder. Some companies use slab wood cut at the mill and hauled to the woods on logging flats. Still others cut wood from white fir, allow it to season, and then deliver it to the yarders on flat cars.

The cost of supplying fuel at one of the smaller compound engines is the time of one man and a horse, or about $3.50 per day. At the 10 by 11 inch and 10 by 13 inch machines, on the East Slope, burning slab wood, the cost is about $4.25 per day for the time of one man and the handling of from 1½ to 2 cords at each machine. Where the split fir wood is used, the amount required daily for a 10 by 10¼ machine is 2 cords, costing $2 each. The large 11 by 13 inch yarders require about two men and a horse to furnish limb wood, at a cost of $5.50 per day. Similarly the 12 by 14 inch machines on long settings require two men and a light team at a cost of $6.50 per day.

The first method of supplying water to donkey engine boilers was by packing in water bags on mules. One waterbuck and mule is required for small boilers, at a daily cost of $3.25. Large boilers require double the force. At present this method is relegated to donkeys used on railroad and chute construction, and donkey engines are supplied almost universally by water conveyed in pipes. Where water is abundant, about one-half of the machines can be supplied by gravity. Where water is less plentiful, from three-fourths to all of the machines must be supplied by pumping. The cost depends upon the distance water must be piped and the number of machines that can be supplied from one pump. Usually two or three machines can be reached from a pump, and the daily cost for hire of pumpman, repairs to pump, and the prorated cost of stringing pipe, is from $1.50 to $2 per machine. The depreciation on pipe and pump varies from 44 cents to 75 cents per day. In localities where water is scarce the best method of supplying water is by means of tank cars. The daily cost, including hauling and depreciation, is from $3 to $3.50 per machine.

Maintenance.—A very considerable cost in yarding is the maintenance of the cables. The life of a main line varies from one-half to 1¼ seasons, depending upon the usage, the amount logged, the amount of rocks, and the general difficulty of logging. Under the favorable conditions in the yellow pine in the eastern Sierras, a 1⅛-inch main line will last from one to two months more than a season and a back line two or three seasons. The average life under most conditions throughout the rest of the Sierras is one season for the main line and two seasons for the back line. Under favorable conditions in the central Sierras, where the soil is loose, the average life of the main line is eight months. On other operations where large machines are used on rough chances the average life is from two-thirds to one season for the main line and two seasons for the back line, with considerable splicing. Usually it will not be far wrong to estimate an average life of one season for main lines and two seasons for back lines. Main lines on Dolbeers last only about two-thirds of a season and the same is true for very large yarders working under severe conditions.

In addition to cables, supplies and repairs are included in maintenance. Supplies consist of oil, grease, tools, blocks, repair parts, etc. The amount required is of course larger for the larger machines. The cost per 1,000 is, however, much the same in different operations under similar logging conditions without much regard to the size of the operation. As a rule, it is from 6 to 9 cents per 1,000. The cost of repairs varies to some extent with the size of the operation. Large operations ordinarily have more efficient shops than smaller ones. The repair crew at the usual donkey camp of from three to five machines is one donkey doctor, one blacksmith, and one blacksmith's helper. At some of the smaller camps the helper is eliminated. On other operations one donkey doctor may look after the machines in two camps. The board and wages of the repairmen amount to from 8 to 10 cents per 1,000, of which it is judged about four-fifths is chargeable to yarding. In addition some of the heavier repair work is done at the mill shop. Also one or two machines are usually overhauled and repaired at the shop each year between logging seasons. Giving consideration to all these factors the information at hand indicates that the cost of maintenance in donkey yarding is normally from 18 to 22 cents per 1,000.

OVERHEAD YARDING.

The use of this system has only just begun in the sugar and yellow pine region. Many operators are considering it as a means of reducing operating costs, but they do not feel that the machinery now on the market meets their requirements. A few loggers have been trying out systems of their own devising during the last two seasons, and one or two standard rigs have been employed.

Two main systems are in use in the large timber of the Pacific Northwest. Both are alike in principle, having a main or standing one supported at either end, upon which a carriage is operated. In one system this main line is slacked off in order to allow the logs to be attached to the carriage; then the main line is tightened, which lifts the log, and the carriage is hauled in. The other system provides that the main line be kept taut and sufficient slack to reach the logs pulled in the skidding line by some slack-pulling device.

The first attempt at overhead yarding in California sugar and yellow pine was made in 1913 with the first-mentioned system. It was continued through 1914 and the company considers the work so successful that a second machine is to be fitted with an overhead rig in the near future. The engine used is a three drum, 12 by 14 inch yarder, equipped with a 1½-inch main or standing line. The usual distance between the spar tree and tail tree is 1,800 or 1,900 feet, but spans of 2,200 feet have been made. The carriage is operated on this standing line by a 1-inch skidding line and a ¾-inch haul-back. The best setting is on the point of a secondary ridge, as the span may then be made across a gulch or small cañyon. The rig is used both for yarding and roading, the plan for roading being to station a yarder at the tail tree and yard in for an additional 1,400 feet. Logs are hauled in one, two, and three log lengths, the average load being about 1,000 feet. A small donkey is stationed at the landing for hauling the logs in the bucking chute and loading. The average output for four summer months was 60,000 feet per day.

Two other similar rigs are being operated experimentally, with some success, in the Sierras. One operator in the northern portion of the East Slope region is using a large steel skidder, known as the universal logger. It is equipped to operate one line as an overhead or two lines as a ground skidder.

The system in which the main line is slackened and pulled sidewise to the logs could hardly be used on National Forest timber sale areas where clear cutting is not practiced. There is reason to believe, however, that under certain conditions the other system can be used, if provision is made in marking the trees for cutting. The cost of overhead machines with double sets of blocks, etc., is from $12,000 to $14,000 each, delivered on the ground. Cables are not included, and the cost of a set ranges from $2,500 to $3,000.

FROM YARD TO LANDING.

When the common yarding point is located at some distance from the landing, a step is necessary which is usually termed chuting or roading. It is usually done in chutes by horses, in chutes with donkey engines, or on the ground with donkey engines. Other possible methods are hauling with slip-tongue big wheels from yarders used on rough ground in the midst of a big wheel logging operation, and the use of overhead systems. Overhead systems similar to those used for yarding may in the future be utilized for roading across canyons, up steep grades, and down rough slopes. Extra supports could be used if necessary. Aerial tramways with frequent supports and several tolleys will undoubtedly be used ultimately in bringing smaller timber down from considerable elevations; for example, red fir for pulpwood.

CHUTE HAULING BY HORSES.

With one exception, chute hauling by horses is used only by firms with small capital. The chutes frequently extend from the woods to the sawmill and may be as much as 8,000 or 10,000 feet in length.

A horse chute is constructed in much the same manner as a donkey chute, but it is lighter and need not be as strong. The poles used are cut either 50 or 60 feet in length, about 8 or 9 inches on the small end, and as large as 16 inches on the butt end. They are laid in two parallel rows about 5 inches apart, the ends being notched and joined. The inner surfaces are then hewed off, in such a manner as to make the width at the top 16 inches and at the bottom 8 inches. A rough road must be provided alongside the chute for the team. All grades must be toward the landing, the minimum advisable being about 5 per cent. The more steeper grades there are, the less chute grease and the fewer horses per team will be needed. The maximum grade employed is about 35 per cent. Logs which have been greased above will run on grades over 30 per cent.

A typical chute-building crew consists of five men and a foreman, with two axmen cutting poles and hewing. The daily cost, including stumpage for the fir poles, is approximately $28. Under rather difficult conditions this crew builds 200 feet of chute per day, at a cost of 14 cents per foot. The cost will on the whole range from 10 to 15 cents per linear foot, or from $530 to $795 per mile.

The customary team consists of eight horses. The number of teams required depends upon the length of the chute and the amount of low grade. The logs are yarded into the chute and made into trains of from 6 to 12 logs each. The team is hitched to the last log but one in the train and the last two logs are dogged together.

The amount hauled daily in a representative chute about $1\frac{1}{4}$ miles in length, with two long flats of 5 per cent grade, is about 40,000 feet. Two 8-horse teams, each with a teamster, are required. The rest of the crew consists of a man at the lower end of the chute and two chute greasers, one of whom shovels frogs. The daily cost is about $40. This is a cost of $1 per 1,000, exclusive of maintenance and grease. On another representative chute about 1 mile in length two 8-horse teams handle about 60,000 feet. A driver and greaser are required with each team. The daily cost is about $39, or 65 cents per 1,000. On another chute something over a mile in length with two branches and a steep pitch in the middle, three 8-horse teams are used. One team is used on each branch and the third works between the foot of the steep grade and the landing. The daily cost is approximately $58. At 50,000 feet daily the cost is $1.16 per 1,000; at 60,000 daily it is 96 cents per 1,000.

The cost of keeping up horse chutes and equipment is not high; probably from 5 to 8 cents per 1,000 will suffice. A very considerable cost in many operations is the grease required to make the logs slide in the chute. The heavier the logs and the lighter the grades the more chute grease is necessary. The grease costs about 4 cents per pound delivered, in barrels of about 400 pounds. The heaviest cost of chute grease noted is for the first horse chute described above, which is in fairly large timber. The daily requirement is two barrels, costing $32, or 80 cents per 1,000. Usually for chutes about a mile in length not more than from one-half to one barrel daily is necessary, which would make the cost from 16 to 30 cents per 1,000. On short chutes with favorable grades in light timber the cost of chute grease may not exceed 5 cents per 1,000.

CHUTE HAULING BY DONKEY ENGINES.

Chute-hauling by donkey engines has been a very popular method of moving logs from yard to landing, the tendency having been to reduce the mileage of railroad spurs by a liberal construction of chutes. Firms using donkey chutes extensively laid out their logging operations with railroads along the principal streams and chutes built up on either side to tap the various tributary watersheds. Some loggers still adhere to this system but the majority are eliminating or greatly shortening chutes by better location and greater mileage of logging railroads. So-called hoists or inclines in connection with logging railroads are just beginning to be used advantageously as a substitute for chutes. However, chutes are of value where timber is out of reach of yarding lines either in pockets below the railroad track or on benches or heads of streams above the track, where the cost of constructing a logging spur or incline would be prohibitive.

Improvements.—Most donkey chutes are constructed of two parallel series of poles laid end to end. The ends are jointed together, and the tops of the poles are always placed in the direction the logs are to be hauled. The poles are laid about 6 or 8 inches apart and the inner sides are hewed off in such a way as to form a trough 10 inches wide at the bottom and 30 inches wide at the top. Cross skids at 10-foot intervals are used to support the chute poles across depressions, and braces are used to prevent spreading. However, where the topography permits the two poles are embedded in the ground, which serves the same purpose. Chute poles are preferably 60 or 70 foot lengths from straight young white fir trees. The usual top diameter is 10 or 12 inches, and the average pole scales about 500 feet. Thus, where few cross skids are required, the scale per mile of chute is about 90,000 feet. With a normal amount of cross skids the scale is about 100,000 per mile. Stream beds and small gulches are crossed by means of cribwork trestles, which add varying amounts to the material required.

Some firms prefer wider chutes called "three pole chutes." Two poles are placed much the same as above, but a third pole is embedded in the ground between them. The average diameter of the outside pole is from 14 to 18 inches, and the average diameter of the bottom pole about 8 inches. The width at the top of the hewing is 30 inches; the width at the bottom is 18 inches; and the depth is 8 inches. The scale is about 10,000 feet per mile greater than that for the two-pole type.

Donkey chutes may be constructed on nearly any necessary grade, with the exception that long minus grades of 28 per cent or over are apt to lead to trouble, through the logs running and jumping the chute. The usual grade of downhill chutes varies from 3 or 4 per cent to 20 or 25 per cent. Adverse grades may occur in such chutes up to 10 or 15 per cent. Usually an extra donkey is required at the top of any long or very steep adverse grade. The severest uphill chute noted is one rising 800 feet in 3,900 feet of length (an average of 21 per cent), with 1,200 feet having an average grade of over 40 per cent. The steepest stretch is 500 feet with an average grade of 54 per cent, within which is a 200-foot pitch of 60 per cent.

The best results are secured from chutes constructed on tangents, but curves may be used where it is necessary to change the general direction of the chute. Short curves or reverse curves are out of the question and usually not more than two or three curves are practicable, even in the longest chutes. A change of 90° in the direction of a chute may be made by means of two long and gradual curves.

Typical chute construction crews vary from a foreman and 17 men to a foreman and 22 men. Each commonly has a Dolbeer donkey engine and two horses. The total monthly cost of the former crew is $1,285, and of the latter, $1,600. The latter crew is typical of an extensive chute logging operation and is made up as follows:

1 foreman	$90 and board.	1 line horse driver	$40 and board.
1 engineer	50 and board.	5 axmen	50 and board.
1 fireman	45 and board.	3 shovelmen	40 and board.
1 woodbuck	40 and board.	1 grading boss	75 and board.
1 waterbuck	40 and board.	5 muckers	40 and board.
2 swampers	50 and board.	1 line horse.	
1 lookout	50 and board.	1 water horse.	

The cost per mile of construction depends upon the configuration of the ground and the accessibility of suitable chute timber. Except for short spurs, the cost varies from about 20 cents per linear foot under favorable conditions to 40 cents per foot for difficult. Construction in open stands, with no rocks and with a fair supply of chute timber, costs, exclusive of stumpage, about $1,000 per mile, of which amount $350 is for clearing and grading. Heavier grading, with some rockwork but no trestles, costs about $1,400 per mile.

A chute with heavy grading and a small amount of trestlework costs about $1,500 or $1,600 per mile. A chute with one large trestle or three or four moderate trestles costs about $1,800 per mile. A combination of large trestles and heavy grading may make a chute cost from $2,000 to $2,200 per mile. The average allowance for the cost of chutes for good-sized logging chances should be from $1,300 to $1,400 per mile for good conditions; from $1,500 to $1,600 for fair conditions; and $1,800 for very difficult conditions. Chute landings cost from $50 to $100 each.

Equipment.—The donkey engines used for chute hauling are commonly larger than those used for yarding. They are of the wide-drummed type usually described as roaders. The size varies with the difficulty and length of the haul. For short downhill pulls a 10 by 12 inch engine may be satisfactory. On the other hand, for steep uphill pulls or very long hauls a 12 by 14 inch or even a 14 by 14 inch roader may be used.

The f. o. b. factory cost of representative roading engines is approximately from $2,650 to $5,450.

TABLE 6.—*Factory cost of representative roading engines.*

Size.	Weight.	Cost.
Inches.	*Pounds.*	
12 by 14	46,000	$4,650
14 by 14	58,000	5,450
11 by 14	36,300	3,450
12 by 12	36,500	3,500
13 by 14	45,200	4,350
10 by 12	27,000	2,650
11 by 13	38,000	3,650
12 by 12	40,000	3,800
Size.	**Main line, 1¼-inch cable.**	**Back line, ⅝-inch cable.**
Inches.	*Feet.*	*Feet.*
11 by 13	4,080	10,600
12 by 12	4,070	9,850
12 by 14	5,100	13,850
14 by 14	8,100	21,400

The prices of smaller machines and the approximate cost of placing the engines on the ground are given under the discussion of donkey yarding equipment.

The size of the cable used for chute hauling depends upon the severity of the haul. For light downhill pulls 1-inch or 1⅛-inch main line may be used. The standard size for long and uphill hauls is 1¼-inch main line, and the usual back line is ⅝-inch. The cost is given under donkey yarding equipment. The cable capacity of representative roaders is shown in Table 6.

On the main line of a chute ground rollers are placed at intervals, and corrugated rollers, mounted on so-called dead-men, are required at curves. Corrugated rollers 8 inches in diameter and 12 inches long are listed at $9 each, and ground rollers 4 inches in diameter and 12 inches in length at $4.50 each. Trip-line blocks similar to those used in yarding are required for the back line, and a large tailblock is placed at the outer end of the line.

Operation.—The bull donkey or roader is stationed at the landing on the logging railroad. A second roader or swing bull may be located farther out along a chute which is very long, crosses over a ridge, or has as many as five yarders. Each bull donkey has a separate crew and main and back lines. The line from the donkey at the landing extends only as far as the swing donkey.

The yarding donkeys are stationed at various points along the chute, usually moving farther out as each setting is completed. A so-called frog is built in the chute at each yarder setting, and the logs are pulled into the chute by the yarder. When several yarders are working on a chute, a branch must be built at each setting for making up trails. If the timber is logged in long lengths, the steam-saw bucking is done in the chute at the yarder.

When enough logs are collected in the chute at a yarder to make a trail, the last two logs are dogged together and the outer end of the main line is attached to the next to the last log. Either double chain-grab hooks or a choker are used for this purpose. The latter is preferred for difficult hauls. The trail of logs is then pulled into the landing. The size of the trail depends upon the grade of the chute and the size of the donkey. For downhill hauls the trail usually contains from 10 to 16 logs, or from 5,000 to 7,000 board feet. On a very heavy uphill the average trail is from seven to nine logs, or from 4,000 to 5,000 feet. The heavier donkeys now being introduced should handle larger trails on downhill chutes.

As a general rule, the more yarders on a chute, the cheaper the hauling. Some firms, usually those using chutes infrequently, place but one yarder on a chute and thereby incur an unnecessarily heavy cost for chute hauling. The only excuse for such a layout is a very short chute with only one or two settings on it. On a downhill chute under 4,000 feet in length with a yarder averaging about 30,000 feet b. m. daily, the crew is as follows: One lineman, 1 bellhop, 1 engineer, and 1 fireman. The bellhop does what greasing is necessary and the lineman does the dogging. Only six trips need to be made daily, which allows considerable time for resting. The daily labor cost is about $12.80. Wood is furnished by one man and a horse, and water is pumped to both machines. Exclusive of cables and chute grease, the average cost per 1,000 feet is about as follows: Operation, 43 cents; fuel, 11 cents; water, 6 cents; maintenance, 12 cents; total, 72 cents per 1,000.

There should be at least two yarders upon a chute from 2,000 to 4,000 feet in length. The crew is larger than that given above by one greaser and one dogger, increasing the daily labor expense by $5. Assuming that the yarders average 30,000 daily, the cost per 1,000 is as follows: Operation, 30 cents; fuel, 8 cents; water, 4 cents; maintenance, 10 cents; total, 52 cents.

The most economical chute hauling occurs where three yarders are located upon one chute with one bull donkey. This is rarely done, and such yarders usually do not average over 25,000 daily. The crew contains one greaser and three doggers in addition to the number for one yarder. The daily labor expense is $23.30. The cost per 1,000 is accordingly estimated as follows: Operation, 31 cents; fuel, 5 cents; water, 3 cents; maintenance, 8 cents; total, 47 cents per 1,000.

On extensive operations, where the chutes are a mile or more in length and have several branches, it is customary to place two bull donkeys and either four or five small yarders upon each chute. The minimum daily output from such a chute is usually about 110,000 and the maximum 130,000. The crew required is 2 linemen, 2 bellhops, 4 or 5 doggers, 2 greasers, 2 shovelers, 2 engineers, and 2 firemen. Three men and two horses are required to supply fuel, at a daily cost of $9.25. The daily labor cost for an output of 110,000 is about $47.25. The cost per 1,000 is approximately as follows: Operation, 43 cents; fuel, 8 cents; water, 5 cents; maintenance, 10 cents; total, 66 cents per 1,000. The cost for a daily output of 130,000 is as follows: Operation, 38 cents; fuel, 7 cents; water, 4 cents; maintenance, 8 cents; total, 57 cents per 1,000.

The cost per 1,000 board feet of the cables used varies with the length of the haul. Under average working conditions 1¼-inch main line and ⅝-inch back line last two full seasons. If the work is light, they should last a season longer. Thus for chutes from 3,000 to 4,000 feet in length with two yarders averaging 30,000 each daily, the cable cost is about 13 cents per 1,000. For a chute over a mile in length with two bull donkeys and an average daily output of 120,000, the cable cost is about 11 cents per 1,000.

In order to overcome friction, portions of the chutes having low or adverse grades are greased with so-called chute grease (crude petroleum). The brand commonly used is sold at 2¼ cents per pound f. o. b. San Francisco. It usually costs about one-half cent per pound more in the woods. A barrel contains approximately 400 pounds and costs about $11 delivered. The amount used depends upon the amount of unfavorable grades. A chute about 5,000 feet in length, of which about one-quarter is upgrade at not to exceed 10 per cent, requires one barrel of grease every three days. The

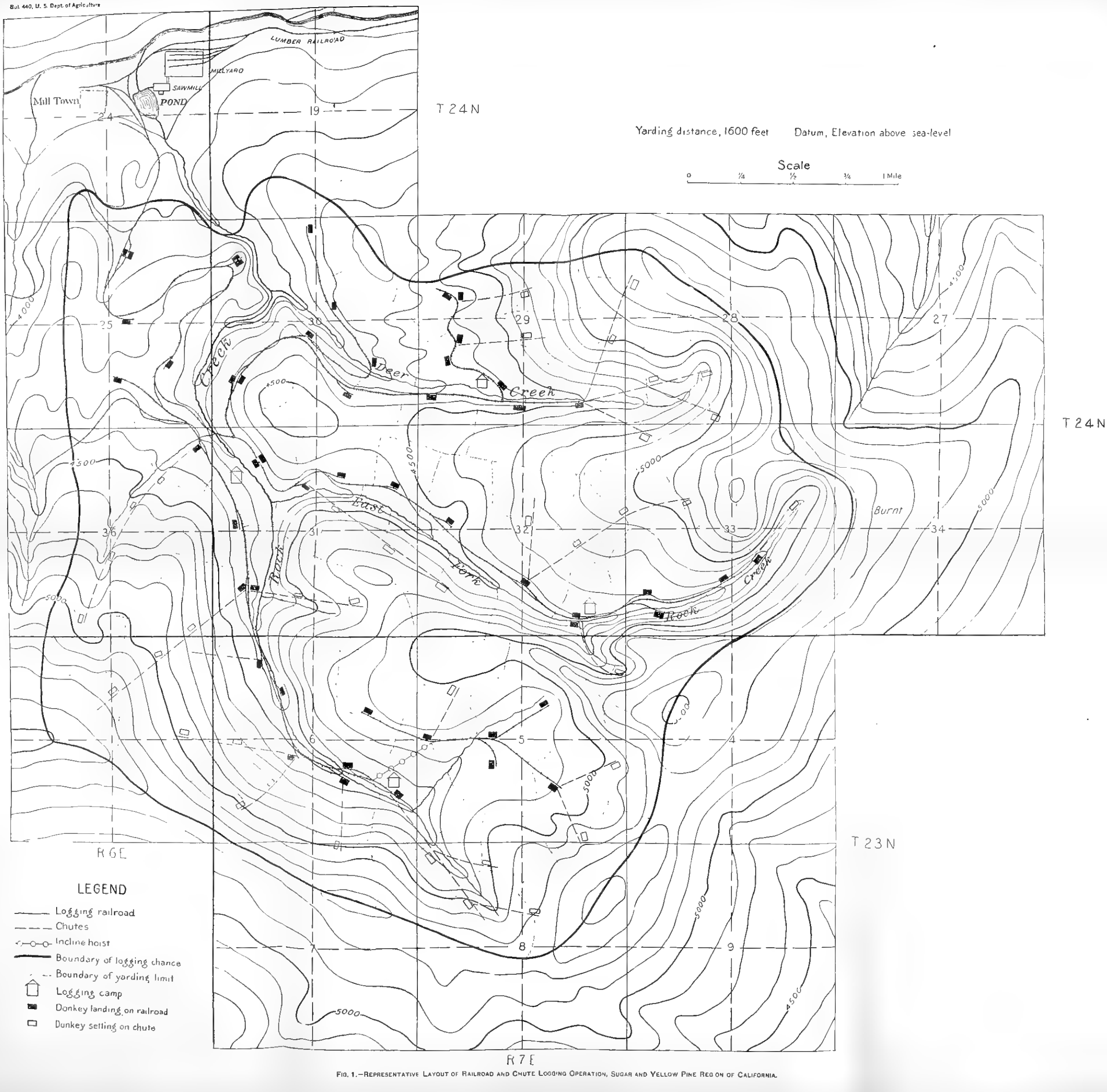

FIG. 1.—REPRESENTATIVE LAYOUT OF RAILROAD AND CHUTE LOGGING OPERATION, SUGAR AND YELLOW PINE REGION OF CALIFORNIA.

average amount hauled daily is 110,000 and the cost for grease about 4 cents per 1,000. On the other hand, a chute 4,000 feet long, with an average adverse grade of 21 per cent and one pitch of 60 per cent, requires four-fifths of a barrel daily for an output of 50,000. The cost is about 14 cents per 1,000. An allowance of 5 cents per 1,000 for chute grease is ample for most chute logging in this region.

DONKEY ENGINE ROADING.

Roading with donkeys on dirt roads is rare, and when used is really a form of double yarding. It is sometimes employed to reach a body of timber too far away for single yarding but not large enough to warrant the construction of a spur or chute. A yarder is placed in the timber and a roading engine stationed at the nearest landing to haul the logs from the yarder to the track. The logs are hauled in the same manner as they are yarded, either singly or two abreast. One roader can serve but a single yarder and the cost is similar to yarding except that the crew is smaller.

A representative roader hauling 30,000 daily, a distance of from 1,600 to 2,000 feet, requires a crew of an engineer, fireman, lineman, blocktender, and whistlepunk. The daily labor cost is $15, or 50 cents per 1,000. Fuel and water cost about $5 per day, maintenance of donkey and tools about 16 cents per 1,000, and cable maintenance about 12 cents per 1,000. The total cost under the conditions given is approximately 94 cents per 1,000.

FROM LANDING TO MILL.

LOADING.

Logs are sent to the mill on log cars, or on trucks, either horse or traction hauled. In general, the operation of loading is the same for trucks as for cars. The simplest method is by hand. It requires small logs and a high landing. This method is infrequently used for loading on railroad cars at the lower end of a chute. In timber averaging five logs per 1,000, six men with peavies may average 50,000 daily at an average cost of 33 cents per 1,000. The only equipment needed is the peavies, which cost about $18 per dozen.

The system of loading termed the "crosshaul" is widely used in truck logging, and sometimes for loading cars. The logs are rolled up skids and onto the truck by means of a chain or cable pulled by a team on the opposite side of the truck. The free end of the cable is fastened to the truck or to the load by a hook and the log is rolled up in the bight. In truck logging the loading is usually done by the truck teamster with a pair of leaders or by the bunch teamster with the bunching team. Thus it is rather difficult to separate the cost from that of bunching or of truck hauling. Ordinarily, for moderate sized logs this cost should be about 30 or 35 cents per 1,000. This system is used in one instance under favorable conditions with a daily output of from 30,000 to 35,000. A crew of one teamster, two loaders, and a team is required, at a daily cost of $10. Besides the horses, harness, and spreaders, the only equipment needed is two peavies for the loaders and 80 feet of loading cable costing about $7.

The most widely used method is by cable and "gin pole." It seems best adapted to donkey logging, and is also used for loading traction trucks. A gin pole, consisting of a log from 14 to 18 inches in diameter by 40 feet high, is erected on the opposite side of the track from the landing and guyed with five cables in such a manner that the upper end is over the center of the track. A block is fastened at the top of the gin pole and a three-fourths inch loading cable passes through it from the loading drum of the engine. This cable may terminate in a hook and be used in much the same manner as the cross-haul, or it may terminate in a crotch line with two end hooks.

Upon one traction logging operation where the loading is done at the lower end of a horse chute, the gin-pole system is used, power being furnished by a Dolbeer donkey engine. The crew consists of 1 engineer, 1 spool tender, 2 loaders, and 1 waterbuck, with a combined labor cost of $14.40 per day. The average daily output is 60,000 and the average cost 24 cents per 1,000. This should probably be increased by 2 cents per 1,000 for maintenance of the donkey and other equipment.

The gin-pole system is widely used where yarders are located at landings along logging spurs. The best results are obtained with cables terminating in a crotch line. The logs are lifted bodily in the air and lowered in place upon the car. Motive power is commonly furnished by a loading spool or a third drum upon the yarder. The crew consists of a spool tender and two loaders, and the total daily cost is $9. Such a crew is ample to handle the output of any yarder; and usually no matter how small the daily output there can be no reduction in the number of the crew. Thus the cost of loading depends primarily upon the average daily output of the yarder. The cost is as follows, according to the daily output: 25,000, 36 cents; 30,000, 30 cents; 35,000, 26 cents; 40,000, 23 cents per 1,000 feet.

The cost of loading by this system at chute landings is cheaper than when each yarder is at a separate landing on the railroad. The reason is that, from two to five yarders being stationed upon a given chute, logs are delivered in quantity up to the maximum capacity of the outfit. The loading crew is the same as at a yarder, except that for a daily output of 120,000 it must be enlarged by one top loader, one loader, and one shoveler. The daily labor cost is therefore about $18.50 per day, or 15 cents per 1,000. At 100,000 daily the cost is about 19 cents per 1,000.

A separate loading engine is probably better as a motive power than a spool or drum upon the logging donkey. It may be either a winch operated by steam from the donkey boiler or a separate engine and boiler. The advantage of the separate engine is that yarding or chute hauling need not be interfered with to favor loading. Further, when a separate boiler is used, loading does not lower the steam in the donkey boiler. The crew and labor costs are the same with a separate loading engine as with a loading spool. Probably from 2 to 4 cents per 1,000 should be added for maintenance; but this extra cost is undoubtedly more than offset by increased efficiency in yarding. A 7¼ by 10 inch three drum loading donkey weighing 11,000 pounds costs $1,550 f. o. b. factory. A 6½ by 8 inch twin drum loading engine weighing about 7,000 pounds costs about $1,000 f. o. b. factory.

One firm uses 6½ by 8 inch loading engines at each yarder or chute donkey. The loading engines are placed on a platform on the opposite side of the track from the landing and the loading is done by means of a short cable exactly as in the horse crosshaul. The crew and cost is approximately the same as given above under the gin-pole system. Another style of loading, used by one large operator in this region, is a crotch line supported by an A frame placed on the front ends of the donkey skids. This A frame is primarily for supporting the yarding line and is obviously modeled upon the principle of the steam skidders. No landings are needed, but loading is difficult, dangerous to employees, and interferes to a certain extent with yarding. The loading crew is the same as that employed at each yarder by the gin-pole system.

Special log-loading machines have not yet proved satisfactory in this region in connection with donkey logging, the cost being higher than if a gin pole were employed. They are, however, very efficient in big-wheel logging operations, for use in loading from log decks, for transferring logs from one car to another, and for picking up logs along the railroad right of way. The type generally used is a self-propelling loader having an inclosed raised platform upon which is located a donkey engine and loading drums. When loading the trucks are raised up and the machine rests on four supports, thus giving room for the empty cars to pass underneath. The loading is done by a cable and crotch line passing through a block at the end of a boom. This boom is in the form of an A frame and may be either rigid or swinging. The cost ranges from $5,500 to $7,500 each. The daily capacity varies from 120,000 to 150,000, depending upon the chance and the size of the logs. It is usually found practicable in large big-wheel operations to deliver from 100,000 to 120,000 daily at each loader. At one representative operation the crew consists of 1 engineer, 1 fireman, 1 woodbuck, 1 top loader, 1 second loader, and 2 hookers, the total daily cost being $19.10. Water is supplied in a tank car at a cost of $3.50 daily. The cost of loading, therefore, averages about 21 cents per 1,000. To this amount should be added 2 cents per 1,000 for maintenance of the machine.

HORSE TRUCK HAULING.

Horse truck hauling is much used at the smaller mills. Where conditions are favorable the trucks may be taken to each tree and the logs loaded with the truck team. In rougher localities the logs are collected at landings by horse skidding or hauling in chutes. Horse trucking permits a rather small woods investment, which adapts it to small operators. Its use is limited to localities where truck roads with moderate grades can be constructed at a reasonable cost. In the level regions big wheels are considered more satisfactory for short hauls.

Except in some of the level pine lands in the eastern Sierras, a road must be constructed to each landing for truck hauling. Such roads should have no adverse grades against the loaded trucks, and not too heavy ones against the empty trucks. Probably 20 per cent is a good maximum. Pitches as high as from 30 to 35 per cent are used in some localities, but at a heavy risk of accidents to stock. Many of the roads are constructed by simply swamping out a right of way and driving over it. However, whenever it is necessary to cross a slope a road must be dug out. Except where solid rock is encountered, the cost of such grading will be about 15 cents per cubic yard. Upon a 20 per cent slope the cost per mile is estimated at from $500 to $700.

The trucks used are of heavy construction, and are usually partly homemade. Frequently the wheels are cross sections of a log. The tires are usually 5 or 6 inches wide. The four-wheeled type is the only kind used. They weigh from 1,800 to 2,000 pounds apiece and cost from $175 to $200, fitted with bunks. Binding chain and draft chain equipment and spreaders add about $40 for each truck. Heavy horses cost from $500 to $550 per span. The daily cost is about $1.50 each. The usual truck team consists of six horses driven with a jerk line, the teamster riding the near wheeler. The braking may be done by the teamster, or a swamper may follow each truck to set the brake.

Several logs are placed on a truck at one time. the average load being from 1,400 to 1,800 feet. Upon an easy mile haul a six-horse truck should make six trips daily with an average load of 1,500 feet, a daily output of 9,000. The cost of labor and team expense is about $13.50 daily, or $1.50 per 1,000. On a ½-mile haul the same truck equipment should have a daily output of about 12,000 at an average cost of $1.12 per 1,000. In one instance, upon a haul varying from 1 to 2 miles from the landings to the mill, six outfits of this character

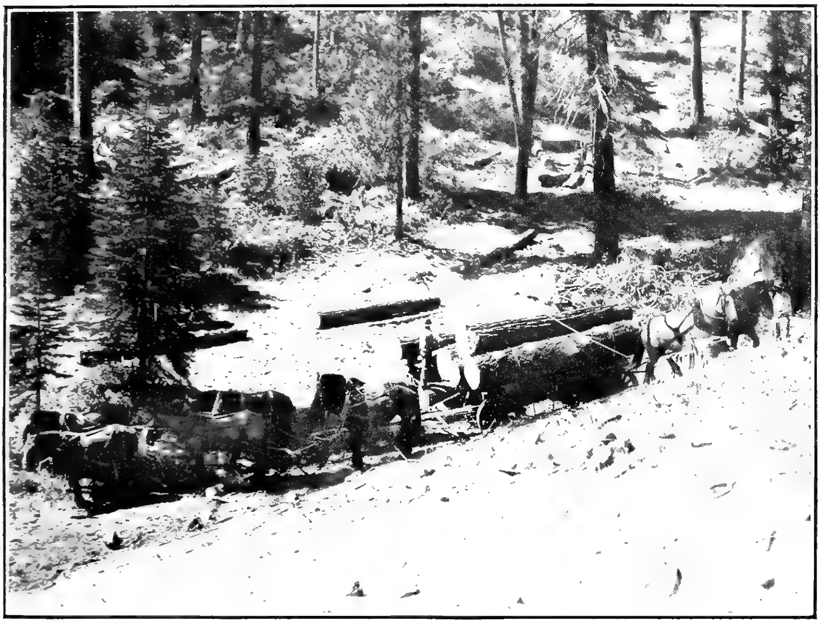

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FIG. 1.—LOADING LOGS WITH A CROSSHAUL IN A HORSE-TRUCK LOGGING OPERATION.

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FIG. 2.—LOADING LOGS WITH A SPECIAL LOADER ON A NATIONAL FOREST TIMBER SALE IN CALIFORNIA.

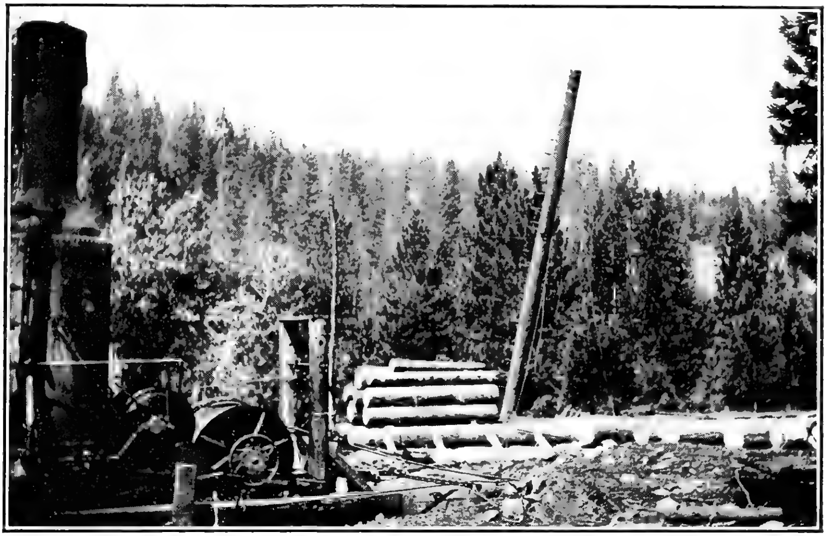

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FIG. 1.—TYPICAL LANDING AND GIN-POLE USED FOR LOADING IN THE SUGAR PINE REGION.

F-12791-A

FIG. 2.—TRUCKS LOADED WITH LOGS READY FOR HAULING WITH A TRACTION ENGINE.

average 40,000 per day. Four trips are made with an average load of between 1,600 and 1,700 feet. The daily cost is about $80, or $2 per 1,000. The cost of upkeep ranges from 8 to 12 cents per 1,000.

TRUCK HAULING WITH TRACTION ENGINES.

Truck hauling with traction engines is used at some small circular mills and at one single-band mill in this region. It does not require any outlay for track, but this is often more than offset by the impossibility of using the engines in wet weather. A rainy summer season will raise havoc with such a logging operation. On the whole, tractions are adapted to truck hauls too long for horses.

The roads required are like those used for horse hauling, except that the roadbed is wider. The cost is consequently greater. Upon a 20 per cent slope the cost of construction, excepting rockwork, is from $625 to $875 per mile. Damp or soft places must be corduroyed with poles.

A common type of traction engine in use for logging is a 110 horsepower road engine, which costs about $5,000 f. o. b. factory. The fuel may be either wood or oil. The boiler is vertical in order that the engine may be used on heavy grades. The weight of the engine is about 17 tons. The outside width of the driving wheels is 9 feet 7 inches, and the width of each wheel is 26 inches. Another engine used is a gasoline engine of the caterpillar type, designed for soft ground. The cost of this 75-horsepower tractor is about $4,500 f. o. b. factory. Its weight is 22,700 pounds and its width is 8 feet.

Two kinds of trucks are used with traction engines. One is four wheeled with either wooden or steel wheels. The common size has bunks 9 feet wide, spaced 10 feet apart center to center. The wheels are 4 feet 4 inches in diameter and the outside tread is 7 feet. One of these trucks with steel wheels costs about $800 f. o. b. factory. The other type is of all steel construction and has only three wheels, one in the middle at the front. It is rated at 10 tons capacity, as against 16 tons capacity for the four-wheeled trucks.

A typical traction logging operation furnishes logs for a single-band mill in the eastern Sierras. The length of the haul varies from 2½ to 3 miles. The maximum adverse grade loaded is 2 per cent; and empty, 14 per cent. Two wood-burning traction engines make two trips each daily with three four-wheeled trucks. The average truck load is 5,000 feet of logs, a daily output of 60,000. The crew of each engine consists of one engineer, one fireman, and one brakeman, at a daily cost of $14.25. Approximately 4 cords of slabwood are required daily per engine. A cord is worth about $2 per 1,000 at the mill, making a total fuel cost of $16 per day for both engines. Oil and grease amount to $1.10 daily per engine. Repairs to engines and trucks for both outfits, including blacksmithing and supply expenses, amount to about $10 daily. The total daily cost is $56.70, or about 94 cents per 1,000. This does not include road repairs.

LOGGING RAILROADS.

Steam logging railroads are the principal means of transporting logs from the woods to the mill. These all have steel rails, there being no pole roads or sawn wooden rails used. The principal reason for the wide use of railroads in logging in California is length of haul. Much of the pine timber is at a considerable distance from trunk line railroads, and heavy investments are required in lumber railroads or flumes. Large mills and heavy output are necessary to warrant these investments. In turn, large mill outputs require extensive logging operations, which necessitate long log hauls. The general topography of the region is rough and mountainous and the logs are too heavy to be handled except by steam. Stream driving is practically out of the question, both because the streams are rocky and difficult of improvement and because sugar-pine and white-fir butt logs will not float. Thus logging railroads are a necessity in practically all operations of any size.

Engineering.—The location of the logging railroad and its spurs is the most important part of the layout of an operation. The type of railroad and the route selected depend upon the period the railroad is to be operated and the amount of timber. The expense of construction should be the least that will serve the purpose required and at the same time permit of a reasonable cost of operation and maintenance. The longer a road is to be used and the heavier the traffic, the better it can be constructed. Logging railroads are constructed more cheaply than even branch trunk line railroads, because the period of operation is shorter. Heavier grades, sharper curves, and poorer roadbed may be used.

Topography is the principal factor influencing the location of logging railroads; but the general plan of logging determines whether they, especially branch lines, shall follow valleys, ridge faces, or the tops of ridges. One reason why the railroad layout for steam yarding differs from that for yarding by horses is that on steep ground yarding engines work more satisfactorily uphill. Main lines are necessarily located and constructed with greater care than spurs. Spurs are constructed wherever they are necessary to bring timber within chuting or yarding distance of the main track. The mileage depends upon the topography, maximum yarding distance, amount of chute hauling, and density of the stand.

In chute logging the main line railroads are constructed along the streams, and chutes are relied upon to bring the timber down to them. Spurs are constructed only to reach chute landings which can not be placed on the main line. The better layout, and one now coming into general use, is to locate the logging railroads on the faces of the slopes and eliminate chutes as much as possible. A large part of the yarding can thus be done directly to the main line. Spurs are constructed to within yarding distance of the remaining timber. Chutes are used only to tap inaccessible coves where the amount of timber will not warrant a spur.

Although it is ordinarily good economy to construct spurs as above, the mileage obviously must not be increased to a point where the saving in yarding is more than offset by the added cost of spurs. For big-wheel yarding, spurs should be placed within one-quarter mile of all timber. For donkey yarding, with favorable conditions for railroad building, the maximum distance from the stump to the track should be from 1,400 to 1,500 feet. Where railroad construction is more difficult, the outside distance should be 2,000 feet, with a usual maximum of 1,600 feet. Usually in locating spurs, the proper settings for the yarding engines are selected and the spur laid out to reach these settings.

Switchbacks are frequently used in order to climb elevations where otherwise the grade would be too steep. As many as four switchbacks are sometimes used in laying out a single spur. Where the rise is considerable, a log hoist or an incline is often cheaper than switchbacks or detours.

There are two gauges used generally for logging roads in this region; narrow gauge, 36 inches in width, and standard gauge, 56½ inches in width. One exception is a road with a width of 1 meter. Narrow-gauge roads can be constructed for less than standard gauge, and the equipment is lighter and less expensive.

The standard gauge is preferred by most operators because a larger tonnage can be handled at a lower cost for operation and maintenance. One of its greatest advantages is that standard equipment, such as trunk-line cars, can be hauled on it. This is of great importance where the logging road connects with common-carrier railroads, because supplies and horse feed can be delivered at the camps in the original cars and any product, such as cordwood or posts, can be loaded for shipment on standard cars.

The narrow gauge is preferred in very rough country, because sharper curves are permissible, less width of roadbed is required, and the construction cost is less. Further, in small or short-time operations the investment for a narrow-gauge railroad and equipment is all that is justified. If a narrow gauge is selected as the proper type all logging railroads on the operation should be of the same gauge.

The maximum grades and curvature allowable on a logging railroad vary with the character of the line and the type of locomotive.

Grades and curvature may be heavier on spurs than on the main line where heavier loads must be handled. A geared engine can negotiate heavier grades and sharper curves than a rod engine. Narrow-gauge equipment can follow sharper curves than standard.

Except where topographic conditions forbid, long main-line logging railroads are usually constructed to permit the use of rod engines. The maximum grades allowed are 3 or sometimes 4 per cent empty and 1 per cent loaded. The sharpest curves are usually 16° for standard gauge and 20° for narrow gauge.[1] In rougher regions even main lines can not be constructed for rod engines at a reasonable cost and geared engines must be used. The maximum grades ordinarily employed are 5 per cent empty and 2 per cent loaded. A heavier grade than 5 per cent can be surmounted, but it is difficult to hold a heavy train on the down grade. The maximum curves used are from 25° to 30° for standard gauge and from 30° to 40° for narrow gauge.

Logging spurs are usually constructed for the use of geared engines with a few cars at a time. The usual maximum grade for empties is 7 or 8 per cent, or even 10 per cent on short pitches, and the maximum for loads about 4½ per cent. The usual maximum curve for narrow-gauge spurs is 50°, though in some instances curves as sharp as 60° are used. The maximum for standard gauge is about 40°. One company using saddle-tank dinkey rod locomotives with a wheel base of 8 feet constructs its narrow-gauge logging spurs with maximum grades of 5 per cent empty and 2 per cent loaded and a maximum curvature of 50°. The maximum grades given above are of course compensated on curves at the rate of from 0.02 to 0.03 per cent per degree.

All of the larger companies employ competent woods engineers to lay out their railroads. The engineers cooperate with the woods superintendent in determining roughly the routes of main-line extensions and spurs. The engineering force then makes preliminary and permanent location surveys and exercises general supervision over the construction. Upon the larger operations the engineer has a crew of a transitman and two helpers. The engineer is usually employed the year round and devotes his time in winter to mapping and cruising. During the summer considerable time of the engineering force is devoted to running land lines and other activities apart from railroad construction. The cost of engineering upon logging railroads varies from $200 to $400 per mile for main lines, depending upon the difficulty, and from $125 to $250 per mile for spurs. In the construction of commercial railroads it is usually customary to figure engineering as 5 per cent of the other costs.

[1] Straight connected saddle-tank locomotives with a short wheel base can be operated over sharper curves than these.

Construction.—The first step in railroad construction, following the final survey, is the clearing of the right of way by felling all trees and cutting out all brush and reproduction. The usual clearing crew is two men, who, under ordinary conditions, clear from 1 to 1½ miles of narrow-gauge right of way per month. Saws and axes are used for felling and swamping, and after the trees are felled the butt logs are bucked off and rolled outside the right of way with jackscrews.

In ordinary sugar and yellow pine stands the cost of clearing the right of way ranges from $40 to $45 per acre. The average width of clearing for a narrow-gauge road is from 20 feet for flat country to 30 feet in broken country. The former is about 2½ acres per mile and the latter about 3¾. Under like conditions the clearing for a standard-gauge road may be 5 or 10 feet wider. The cost for a narrow-gauge right of way is ordinarily from $100 to $160 per mile, and for a standard-gauge from $125 to $200 per mile.

Before grading is commenced all stumps which will interfere with excavation for the roadbed must be removed. This is usually done by blasting with 5 per cent blasting powder. An iron bar is driven under each stump and a small piece of giant powder exploded at the bottom of the hole. The cavity thus formed is loaded with blasting powder, and the explosion of this charge blows out the stump. Average loads are one-fourth box (12½ pounds) for a 12 to 16 inch stump, 1 box for a 30 to 36 inch stump, and from 2 to 2½ boxes for a 60-inch stump. Yellow pine is the most difficult to blast out and sugar pine and incense cedar the easiest in about the ratio of 1¼ boxes for a 30-inch yellow pine to three-fourths box for a 30-inch incense cedar.

Blasting powder comes in 50-pound boxes, which cost from $3.25 to $3.75 each delivered on the works. Counting in a man's labor for from one to two hours, caps, a stick and a half of giant powder, and the necessary fuse, the cost of removing a 36-inch pine stump is from $4 to $5. The cost of blasting stumps per mile varies with the species, number, and size of the stumps. In normal sugar and yellow pine stands it averages from $200 to $250 per mile, respectively, for narrow and standard gauge. Some miles run as high as $400 each.

When the stumps have been removed the right of way is ready for the grading of the roadbed. The width of the roadbed varies from 11 to 12 feet for narrow gauge and from 13 to 14 feet for standard gauge. Sidehill cuts are commonly made in such a manner that two-thirds of the width of the roadbed is a solid cut and the remainder a fill. In most cuts the sides are sloped at one-half to one, which is the equivalent of a horizontal distance of 6 inches to a vertical distance of 1 foot. In very soft soil it may be necessary to use a slope of one to one. The usual slope for an earth fill is one and one-half to one for most soils encountered in railroad building in this region.

Most of the grading is done with pick and shovel. This is particularly true of sidehill work where the bank may be picked away and shoveled to the lower side. Light work on fairly level ground is done in the same way, the dirt being borrowed from ditches or borrow pits. Frequently moderate sized cuts and fills, under favorable soil conditions, are handled in the same manner, the material from the cuts being mostly wasted and that needed for fills borrowed.

Pick and shovel work is usually done by day labor, as are all other parts of railroad construction. As a rule the men work in crews without any particular task for each. Very good results are secured, however, by assigning each man to a 25-foot station. This promotes rivalry, as the men do not like to be left behind when their neighbors have finished and gone ahead. The cost of digging and spreading dirt is commonly from 15 to 25 cents per yard for common loam, and from 30 to 35 cents for heavy soils.

In larger cuts the dirt is moved to adjacent fills with wheelbarrows. Even better success is secured by using light two-wheeled hand dump carts holding from one-third to one-half yard. Three men handle each cart, first filling it and then wheeling it out to the fill. Planks are laid in the bottom of the cut to facilitate wheeling. The cost of such work, where rocks are not encountered, ranges from 30 to 50 cents per yard. In very large cuts it is sometimes the practice to lay a temporary track and remove the dirt by shoveling it by hand onto a train of flat cars, which is hauled out on the line by an engine, the dirt being used for ballast.

A typical pick and shovel crew consisting of a foreman, a blacksmith, a man with a team and wagon, and 44 muckers, costs $2,500 per month. Working under rather favorable conditions, with soil that is easily worked and a moderate amount of soft rock, this crew grades about 85 stations per month, the average amount of material moved per station being about 60 yards. This is done at a cost of $1,560 per mile, or 49 cents per yard.

Many firms supplement the pick and shovel crew by a second crew, using teams and scrapers for grading the larger cuts and fills. A typical crew of this sort contains a foreman, 3 teamsters, 3 men holding slips, 5 muckers, and 3 two-mule teams. The cost is about $3.20 per hour, and earthwork can be done for from 20 to 25 cents per yard for distances not over 100 feet. So-called slips are used to scrape up and transport the dirt after it has been loosened by the muckers with picks. Wheeled scrapers are rarely used. In some instances ordinary one-horse dump carts are employed with success for moving dirt some distance. Steam shovels are infrequently used in cuts on extensive main line roads, usually lumber roads rather than logging roads. Steam shovels may also be put to good use in loading gravel for ballast. A 1½-yard dipper steam shovel suitable for heavy work costs $8,060 at San Francisco. A smaller revolving shovel with a seven-eighth-yard dipper costs $5,640.

Solid rock and loose rock that can not be loosened with a pick must be broken up by blasting before excavation. Hand drills are used in making the required shot holes. These holes are loaded with sticks of high-grade giant powder, costing 11 or 12 cents per pound, and the charges exploded by caps and fuse. Soft rock and decomposed granite are often blasted more effectively by loading burrows with large quantities of low-grade powder, such as is used for removing stumps.

Average costs may be calculated by classifying the material to be moved. Light earthwork on spurs and in smooth regions can usually be done at an average cost of from 15 to 25 cents per cubic yard in place. Heavier dirt work will average from 30 to 40 cents per yard. Ordinary earthwork with a moderate amount of soft rock averages from 40 to 50 cents per yard. The cost of grading with a normal amount of rock ordinarily averages from 50 to 60 cents per yard. Most of the logging roads on the west slope of the Sierras are graded at this average cost. Soft rock requires an expenditure of about 75 cents per yard and removing solid rock costs $1 or more per yard.

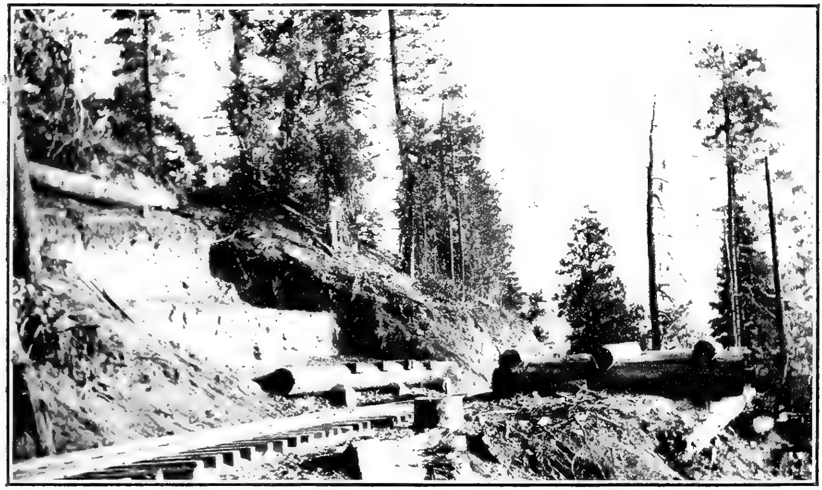
The easiest grading occurs in the flat sugar and yellow pine stands of the northeastern part of the State, where the average cost for standard-gauge spurs is often about $800 per mile. Some miles are graded for as low as $200 or $300. The next cheapest work is in the yellow pine of the eastern Sierras, where, in moderately rolling regions, the average cost is from $900 to $1,000 per mile. For the easier grading in moderately rough regions on the west side of the Sierras, where about from 50 to 70 yards are removed per station, the cost is from $1,500 to $2,000 per mile. The average cost in this part of the region for fairly rough localities is from $3,000 to $4,000 per mile. The steeper and rougher regions necessitate an average grading cost of from $5,000 to $5,500, and on some lines the cost may be as high as $7,000 per mile. An unusually large amount of rock-work runs the cost of some miles up to $12,000. For most of the sugar pine stands the average cost of grading main lines and spurs is between $3,500 and $5,000 per mile. The cost of grading a narrow-gauge roadbed is from 10 to 20 per cent less than a standard gauge.

For temporary lines it is frequently cheaper to construct cribbings or trestles than fills. Cribbings are used in shallow depressions, and consist of large logs laid at right angles to the track 12 feet apart from center to center, Two other logs are laid lengthwise on these for stringers. The cost for an average height of from 4½ to 5 feet is from 50 to 60 cents per linear foot, exclusive of stumpage. From 400,000 to 450,000 feet board measure of logs are required per mile.

Two types of frame trestles are in use on logging railroads, namely, rough timber and sawed timber trestles. Rough timber is usually used on spurs or lines which will be in use for a short time only, because it decays more quickly than sawed timber. Its durability is increased, however, by peeling the poles. Where suitable pole timber is available, a rough timber trestle can be constructed more cheaply than one with a sawed frame.. Rough timber trestles are commonly built with bents 15 feet apart from center to center. Each bent contains a log for a sill and four smaller logs for posts. Rough timbers are used for caps and stringers, but the bracing is done with sawed 3 by 8 inch planks. The usual method of building such a trestle is to place a Dolbeer donkey at the site and skid the sills, posts, and caps in from the near-by timber. The bents are then built on the ground and raised to a vertical position by the donkey engine. In one instance a crew of 18 men working in this manner constructed a standard-gauge rough timber trestle 255 feet long, with a maximum height of 38 feet in eight working days, at a labor and supply cost of $416. The log scale of the material involved was as follows: Caps, 2,700 feet; stringers, 6,900 feet; posts, 9,420 feet; sills, 10,400 feet; total, 29,420 feet. In addition, 4,800 feet of braces were required. Allowing $1 per 1,000 stumpage on the rough timber and $12 per 1,000 as the cost of braces, the total cost is $503. Thus, for this example, the cost per 1,000 is $14.80, and the cost per linear foot is $1.97.

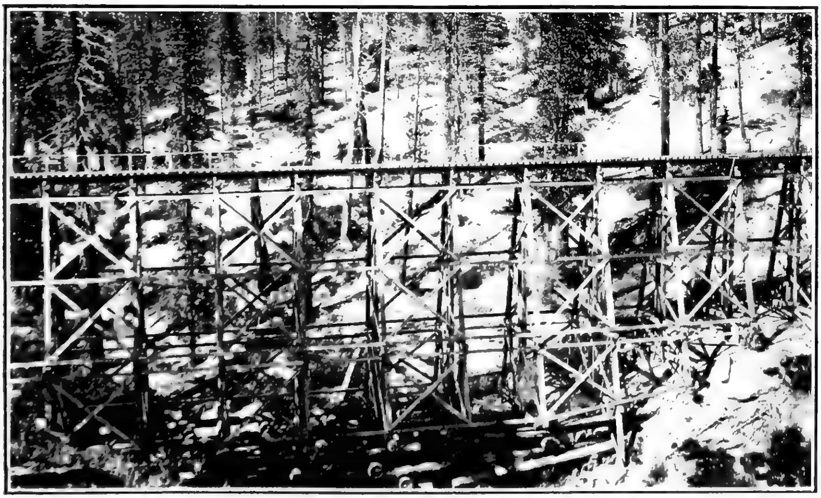
Sawed timber trestles are likewise constructed with bents 15 or 16 feet apart. Each bent rests upon a sill which may be either a sawed 10 by 12 inch timber or a cedar log. Four 10 by 10 inch posts are used in each bent, the two outside having a batter of 2 or 3 inches per foot. Each bent has a 10 by 12 inch cap 12 feet in length. Three 6 by 16 inch stringers are placed under each rail to support the ties. The bents are braced with 2 by 8 inch or 3 by 8 inch sway and collar braces and from 3 by 8 inch to 4 by 8 inch stringer braces. These dimensions are for standard-gauge logging trestles The caps and sills are shorter in narrow-gauge trestles and some of the braces may be lighter; therefore, from 5 to 10 per cent less timber is required. Otherwise the cost is very little less for a narrow-gauge trestle, because the work of erection is about the same.

The cost of frame trestles is usually figured at so much per 1,000 feet board measure of the lumber used. This cost is made to include lumber, bolts, and other supplies, and the labor of building the foundations and framing the trestle, the lumber being usually charged in at $12 per 1,000. The costs of several representative standard-gauge frame trestles recently constructed on logging roads are given in Table 7.



F-15944-A

FIG. 1.—MAIN LINE LOGGING RAILROAD AND DUG LANDING ON TYPICAL LOGGING OPERATION IN THE SUGAR AND YELLOW PINE REGION.

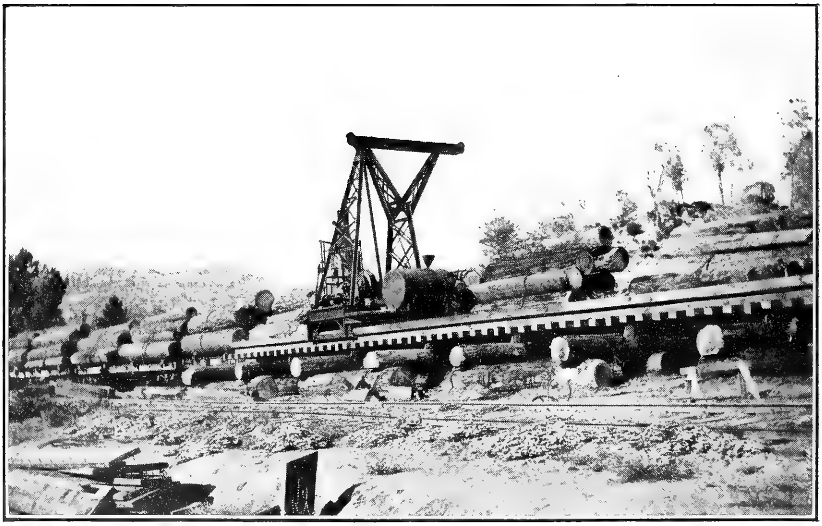


F-15867-A

FIG. 2.—FRAME TRESTLE ON LOGGING RAILROAD IN THE SUGAR PINE REGION.

F-30927

FIG. 1.—LOADED LOGGING CARS READY FOR TRANSPORTATION TO THE MILL POND.



F-15952-A

FIG. 2.—SPECIAL UNLOADING RIG AT THE MILL POND.

Train of loaded flat cars set in ready for unloading.

TABLE 7.—*Cost of standard-gauge frame trestles.*

Length.	Maximum height.	Feet, board measure.	Total cost.	Cost per 1,000.	Cost per linear foot.
Feet.	*Feet.*				
620	52	105,000	$2,800	$26.66	$4.52
652	28	60,000	1,565	26.08	2.40
762	8	68,000	1,704	25.06	2.23
202	32	28,000	743	26.[illegible]	3.68
140	34	19,000	487	2[illegible]	3.34
238	31	31,000	724	23.35	3.04
272	41	45,000	1,030	22.89	3.77
144	54	30,000	713	23.76	4.95

It thus appears that the cost of constructing sawed-timber trestles in this region varies from $23 to $27 per 1,000 feet board measure, depending upon the difficulties of construction, particularly the amount of work necessary in excavating foundations. A good average figure for trestle construction is $25 per 1,000. The cost per linear foot may be roughly calculated as from $2.25 to $2.75 for trestles with a maximum height of from 10 to 25 feet, from $2.75 to $3.50 for a maximum height of from 25 to 35 feet, from $3.50 to $4.50 for a maximum height of from 25 to 50 feet, and from $4.50 to $5 for a maximum height of from 50 to 55 feet.

Most of the ties used on logging railroads are sawed at the mill and hauled back to the woods. The material is usually white fir or defective cedar. Split cedar and hewed white fir are used in some instances. The usual size on standard-gauge roads is 7 by 8 inches by 8 feet. Some roads use with equal success ties 6 by 8 inches by 8 feet. The first size contains $37\frac{1}{3}$ feet board measure, and the second 32 feet. The usual narrow-gauge tie is 6 by 8 inches by 6 feet. Sometimes, in order to cut three ties from a 16-foot timber, the length is made $5\frac{1}{3}$ feet. The contents of a sawed narrow-gauge tie is 24 feet board measure.

The number of ties per mile varies with the size of the rail, the weight of the locomotive, and the efficiency of the roadbed. Upon permanent main-line logging roads the usual number is 16 per rail, or 2,816 per mile. Most main-line roads and spurs have 17 per rail, or 2,992 per mile. Some spurs have 18 per rail, or 3,168 per mile. The volume in feet board measure of 2,992 sawed ties per mile is 111,600 for the larger standard-gauge ties, 95,700 for the smaller standard-gauge size, and 71,800 for narrow-gauge ties. At $12 per 1,000 the cost per mile is, respectively, $1,339.20 for the first, $1,148.40 for the second, and $861.60 for the third. Where suitable young timber is available, hewed standard-gauge ties can sometimes be delivered at the track for from 20 to 25 cents each. At 20 cents each, the cost is approximately $600 per mile.

The size of rails also varies with the size of the locomotives and the maximum loads. As a rule, the use of heavy rails pays. They depreciate less in use and in lifting and relaying. They can be used with fewer ties and on a poorer roadbed than the lighter rails. The weight of the steel rails now used varies from 30 to 60 pounds per yard.

The use of 30-pound rails is rare and is limited to narrow-gauge roads with light locomotives. A few companies use 35-pound rails on standard-gauge roads with 32-ton locomotives, but such light rails are no longer popular. For narrow-gauge roads, 45-pound steel is thought to give the best satisfaction. For standard-guage roads, 50 or 56 pound steel is the choice of the most up-to-date companies. A logging superintendent who lifts his spurs several times in a season thinks that 56-pound steel is the cheapest in the end. Rails weighing 60 pounds per yard are used on main-line logging roads for heavy locomotives.

Rails are ordinarily sold by the gross ton of 2,240 pounds. The number of gross tons per mile for any size rail may be obtained by multiplying the weight per yard by 11 and dividing by 7. The weight in tons per mile of several representative sizes of rails is as follows:

Weight per yard.	Weight per mile.	
Pounds.	*Tons.*	*Pounds.*
35	55	....
40	62	1,920
45	70	1,600
50	78	1,280
56	88	....
60	94	640
65	102	320
70	110	....

The prices of steel rails fluctuate from month to month and season to season. The following 1914 prices on new rails f. o. b. San Francisco, carload lots, are, however, sufficiently exact for estimates:

25 to 45 pounds per yard, $1.55 per hundredweight, or $34.75 per gross ton.
50 to 90 pounds per yard, $1.835 per hundredweight, or $41 per gross ton.

The freight rates on rails and rail fastenings from San Francisco vary from 30 cents per hundredweight for the nearest points in the Sierras to 80 cents per hundredweight for points in northern California.

First-class inspected relaying rails are quoted f. o. b. Pacific coast terminals at the following prices:

25 to 45 pounds, $30 to $32 per ton.
56 to 60 pounds, $33 to $35 per ton.

The common rail length is 30 feet, which gives 352 joints per mile. The usual method of splicing joints is by means of angle bars rather than fishplates. The cost of standard angle bars f. o. b. San Francisco is approximately $2.05 per hundredweight. The weights of angle bars for three typical weights of rail are as follows:

Weight of rail.	Per joint.	Per mile.
Pounds.	*Pounds.*	*Pounds.*
35	12.65	4,450
45	18.75	6,600
60	32.40	11,400

Four bolts and nuts are required at each rail joint. They come in kegs of 200 pounds each, at a price f. o. b. San Francisco of about $2.65 per hundredweight. With hexagonal nuts the quantity required per mile is as follows:

Weight of rail.	Size of bolt.	Number of nuts in a keg.	Kegs per mile.
Pounds.	*Inches.*		
35	$2\frac{3}{4}$ by $\frac{5}{8}$	410	3.4
40–45	3 by $\frac{5}{8}$	395	3.6
50 and up	3 to $3\frac{1}{2}$ by $\frac{3}{4}$	245–270	5.2–5.7

The cost of standard-size railroad spikes, $5\frac{1}{2}$ by $\frac{9}{16}$ inches, f. o. b. San Francisco, is approximately $2 per hundred weight, or $4 per keg of 200 pounds. The bulk of the spikes used are of this size, though smaller sizes are used for light rails on narrow-gauge lines. The average number of kegs required per mile is about as follows:

Weight of rails.	Size of spikes.	Number of spikes per keg.	Kegs per mile.
Pounds.	*Inches.*		
45–90	$5\frac{1}{2}$ by $\frac{9}{16}$	375	28–30
40–56	5 by $\frac{9}{16}$	400	27
30–45	$4\frac{1}{2}$ by $\frac{1}{2}$	530	20

Both stub and split switches are used in this region. The better lines are now using the latter type. Two-way split switches with ground throw cost about $40 each, and the installation costs about $12. A stand costs $15 additional. A three-throw switch costs about $60.

The track laying is usually done by hand. The custom is to deliver the ties and rails at the point of construction on flat cars with a locomotive. The track-laying crew then carries the ties ahead, places them in position, and lays the rails by hand. As the work progresses, fresh supplies of ties and rails are moved ahead on a push car. The same crew which lays the track commonly does the surfacing, and the costs are commonly reckoned together.

For a standard-gauge railroad the cost is about $200 per mile for laying the track and from $350 to $500 per mile for surfacing, depending upon the difficulty and thoroughness of the work. A good average figure for laying and surfacing is $600 per mile. Because the materials are lighter and the roadbed is narrower, the cost of laying and surfacing a narrow-gauge railroad is ordinarily less. The usual cost for a narrow-gauge ranges from $450 to $550 per mile. Under favorable conditions on one narrow-gauge road a crew of 15 men and a foreman, at a daily cost of $37, lay and surface an average of 400 feet of track per day. These costs are for main lines and important spurs. For spurs used only a short time the cost of surfacing may not be over from $150 to $200 per mile, though the cost of laying track remains the same.

As the various spurs are logged out the track is lifted and transported to new spurs. Rails may be lifted once every season for from 15 to 20 years. Ties may usually be lifted about three times. The cost of lifting by hand when both rails and ties are taken up is about the same as laying track, or a little more, say from $200 to $300 per mile.

Logging railroads are commonly operated by telephone. The cost of a tree line is from $30 to $40 per mile. Ordinarily, logging roads need be at no expense for fencing.

Equipment.—The equipment, or motive power and rolling stock, consists of steam locomotives and cars or trucks. Locomotives are of two general types; rod, or straight connected, and geared. The choice between the two kinds is determined by the grades and curvature of the road.

Rod locomotives are used for the longer hauls on main-line roads. They make better time and cost less for maintenance. The cost of operation per 1,000 feet board measure is thus less than for geared engines, especially for hauls over 15 miles in length. The weight of a rod locomotive for main-line work varies with the maximum grades and the maximum load. The usual sizes are from 40 to 75 tons. The larger engines are used for long lumber or log hauls. The approximate cost prices on the Pacific coast and the tractive power of rod locomotives follows:

Total weight.	Weight on drivers.	Load at slow speed.				Cost.
		Level.	1 per cent grade.	3 per cent grade.	4 per cent grade.	
Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	
42	31	1,240	415	140	90	$9,500
55	40	1,630	545	185	125	11,200
67	49	1,970	665	225	150	13,900
71	57	....	....	....	....	14,500

Because of the general roughness of the topography, most of the logging in sugar and yellow pine is done by geared engines. The weight of geared locomotives likewise depends upon the maximum grades and the loads to be hauled. Operators are gradually adopting heavier engines. The smallest locomotive used is a 24-ton engine, which is capable of handling 20,000 feet board measure on slight adverse grades and the empty trucks up a 6 per cent grade on a narrow-gauge road. Locomotives weighing from 32 to 42 tons are commonly used on narrow-gauge lines for switching and main-line hauls of moderate length. Such locomotives handle trains of 40,000 feet board measure. Locomotives up to 56 and 60 tons are used for long and heavy hauls on narrow-gauge lines. With adverse grades of 2 per cent such locomotives haul trains of 55,000 feet board measure. Larger locomotives weighing 65 and 70 tons are used for main-line hauls on standard-gauge roads. These locomotives pull nine empty 41-foot flats up a continuous 5 per cent grade and haul a load of 60,000 up an adverse grade of 2 per cent. Geared locomotives weighing 90 tons are used for switching by one concern, but they appear to be too heavy for the usual logging railroad track.

Three standard makes of geared engines have been used thus far in California pine logging. The 1914 catalogue prices are as follows:

TABLE 8.—*Prices of standard makes of geared locomotives.*

Weight.	Factory price with steam brake.	Freight to California.	Air brakes.	Total.
Tons.				
18	$3,600	$510	$400	$4,510
20	4,100	590	400	5,090
24	4,560	660	450	5,670
28	5,320	720	450	6,490
32	5,760	780	500	7,040
36	6,480	930	500	7,910
42	6,930	830	500	8,260
50	8,000	950	500	9,450
60	9,000	1,110	500	10,610
70	10,150	1,190	550	11,890
80	13,000	1,430	550	14,980
90	14,000	1,540	550	16,090

Weight.	Load on dry rails.				Air brakes.	Oil burners.	Total cost f. o. b. San Francisco.
	Level.	1 per cent grade.	4 per cent grade.	7 per cent grade.			
Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*			
32	1,568	425	113	54	$350	$400	$7,290
42	2,058	558	149	72	400	500	8,790
60	2,940	798	213	102	400	500	11,115

Oil-burning equipment can be installed for from $400 to $500 per boiler. All locomotives under 42 tons in weight are loaded on flat cars; larger locomotives are shipped on their own trucks. For from 32 to 80 ton locomotives the shipping weight is from 5 to 8 tons less than the working weight.

Three types of log cars are used: Separate trucks, skeleton cars or connected trucks, and flats. Separate trucks are used on several narrow-gauge roads. They are necessary wherever long logs must be transported on crooked roads. The cost of upkeep is so large and the danger of accident so great that for pine it is usually better to buck all logs into short lengths and use skeleton or flat cars. Because of their freedom from accidents, flat cars are believed to be the best. Most firms are now using them. They may be used on any grades and on curves up to 60° on narrow-gauge tracks. Air brakes are now used on all roads except a few of the shorter narrow-gauge lines. Pin couplers are still used on most narrow-gauge roads, even for flat cars. Automatic couplers are used on most of the standard-gauge roads. Practically universal use of air brakes and automatic couplers is only a question of time.

The separate trucks used on narrow-gauge roads with hand brakes have about 30,000 pounds capacity and are 21 feet over all (two trucks); the average load is from 2,000 to 2,500 feet. The flats used on narrow-gauge roads are 24 feet in length by 7½ or 8 feet wide, and have a rated capacity of 40,000 pounds. The average loads range from 3,000 to 4,500 feet. Two types of flats are used on standard-gauge roads. The smaller is a 26-foot car with 60,000 pounds capacity; the average load is from 4,500 to 5,000. A 41-foot flat is, however, preferred, the rated capacity being 80,000 pounds; the usual load is 7,000 or 8,000 feet.

The cost of 21-foot wooden trucks equipped with air brakes and delivered on the Pacific coast is about $275 for 30,000 pounds capacity, $310 for 40,000 pounds capacity, $370 for 50,000 pounds capacity, and $470 for 50,000 pounds capacity. A San Francisco firm quotes 60,000 pounds capacity trucks rebuilt from trunk-line equipment at $425 each, and connected trucks with 80,000 pounds capacity, equipped with patent bunks, at $750 each. Both types have air brakes and automatic couplers. Another coast manufacturer quotes the prices in Table 9, f. o. b. San Francisco.

TABLE 9.—*Prices of trucks with air brakes and automatic couplers.*

Capacity.	Description.	Length.	Width.	Weight.	Price f. o. b. San Francisco.
Pounds.		*Feet.*	*Feet.*	*Pounds.*	
100,000	All steel trucks			22,000	$850
80,000	Steel bolster trucks			20,400	695
50,000	....do			18,000	570
40,000	....do			17,000	435
80,000	Connected truck	40	9	19,000	735
80,000	Flat (wood)	41	8½	28,500	835
80,000	Flat with bunks			28,500	900

Many firms build their own logging cars, particularly those using narrow-gauge flat cars. The complete cost of building such flats, 24 feet in length, is commonly about $600. Each car is equipped with chains for binding the logs, which cost, per car, from $10 to $20.

Upon the smaller operations usually about three sets of cars are required; one at the pond, one on the road, and the other in the woods. Larger operations require at least four sets of cars, a loaded and an empty set being in the woods all of the time. In most instances a few extra cars are in the repair shop or being used for other purposes. With a hauling distance of 10 miles or more, at least two locomotives are required; one for the main-line haul and the other for switching the loads out to the main line.

Upon a road 16 miles in length, including spurs, one 35-ton main-line rod engine, one 42-ton geared engine, and 80 flats 24 feet in length are required for a daily output of 160,000. The usual train load is 16 flats. A company operating 11 miles of railroad with heavy grades has one 32-ton and two 42-ton geared locomotives and seventy 24-foot flats. The usual train is 14 cars and the daily output is about 250,000. A firm with a daily output of 220,000 has 20 miles of logging railroad with heavy grades and 10 miles of spurs. Two geared locomotives, one 56 and the other 60 tons, are operated on the main line. Two 37-ton geared locomotives are required for switching on the spurs. The usual train load is 18 cars, and a total of one hundred and fifty 24-foot flats are required.

Operation.—A general idea of the operation of logging railroads has already been given in the discussion of equipment. The crew required, as well as the amount of equipment, depends upon the daily output and the resistance. Upon small operations one locomotive and crew is sufficient. This engine hauls the empties out to the woods, switches them to the yarders, picks up the loaded cars, and takes the train to the mill. In most instances two trips are made daily. Larger operations with longer railroads keep one locomotive in the woods distributing empties and switching out the loaded cars to a point where they are picked up by the main line locomotive. Still larger operations have two main-line locomotives and two or more locomotives switching in the woods.

Geared locomotives are slower than rod engines and more of them are necessary for the same mileage. Enough crews and locomotives should be maintained on any operation to keep the loaders supplied with empty cars. Delays caused by lack of cars materially increase the cost of yarding and loading.

One train crew is assigned to each locomotive. On most logging railroads the customary crew consists of a conductor, brakeman, engineer, and fireman. The daily labor cost is from $15 to $16 for 10 hours work. Overtime at the regular rates is allowed for any work in excess of this period. On long runs or heavy grades this crew may be increased by a second brakeman, thus adding from $3 to $3.50 to the daily cost. Where there are several crews the services of a dispatcher are required.

On account of the danger of setting fires with sparks from wood, the common fuel for locomotives is oil. Burning oil also renders a locomotive somewhat more efficient than when wood is used. Oil is also easier to handle and saves considerable time. The amount consumed daily depends upon the size of the locomotives and the resistance of the road. For example, a 35-ton rod engine on a 12-mile main-line haul, with grades of 1 per cent loaded and 2½ per cent empty, consumes 10 barrels daily. A 70-ton engine on a 10-mile main-line haul, with grades of 2 per cent loaded and 5 per cent empty, consumes 20 barrels daily. The present cost of fuel oil delivered at the various logging railroads in California ranges from $1.10 to $1.30 per barrel. A good figure for estimating fuel costs is $1.20 per barrel.

Where fuel oil is not obtainable at a reasonable cost, which is usually at mills with lumber flumes, wood must be used—either slab wood or split white fir. The cost is from $1.75 to $2.25 per cord, besides the time spent in loading it on the tender. A 42-ton geared locomotive working fairly hard requires about 7 cords per day. Thus it appears, eliminating the extra efficiency of oil and loss of time on the part of the train crew, that the daily cost is much the same. One operator whose wood costs $2.50 per cord calculates that he saves $1.50 daily on a 35-ton locomotive, and states that the oil-burning locomotive handles 16 cars and a wood burner but 14.

The expense chargeable to railroad transportation of logs, in addition to train labor and fuel, includes the cost of lubricating oil and waste, upkeep of locomotives and cars, and upkeep of the roadbed. Sometimes unloading is also included. The minimum expense, even for the shortest hauls, is from 35 to 50 cents per 1,000. The cost on a 5-mile haul where one locomotive and crew is employed to get out 60,000 daily is approximately 60 cents per 1,000, divided into 32 cents for labor and fuel, 12 cents for maintenance of way, 11 cents for repairs to rolling stock, and 5 cents for oil, waste, and supplies.

The cost for one haul of from 14 to 16 miles with favorable grades and good roadbed is 84 cents per 1,000, approximately as follows: Train labor, 20 cents; fuel, 14 cents; maintenance of way, 23 cents; supplies, 3 cents; inspection and maintenance of equipment, 24 cents per 1,000. Two oil-burning locomotives are required for a daily output of 160,000. Upon a difficult 12-mile main-line haul two geared locomotives move 280,000 daily at a cost of 94 cents per 1,000 as follows: Labor and dispatching, 22 cents; fuel, 18 cents; oil, waste, etc., 2 cents; labor for maintenance of way, 18 cents; supplies for maintenance of way, 8 cents; repairs to locomotives, 17 cents; and repairs to cars, 9 cents per 1,000.

In general, under normal conditions the total cost of railroading, including maintenance, is approximately as follows: From 50 to 60 cents per 1,000 for from 4 to 5 miles, from 70 to 80 cents per 1,000 for from 7 to 10 miles, from 80 cents to $1 per 1,000 for from 10 to 16 miles, from $1 to $1.20 per 1,000 for from 18 to 22 miles, and from $1.30 to $1.50 per 1,000 for from 25 to 35 miles.

Very few rates for hauling pine logs in California have been established on common-carrier railroads. Three such representative rates are: 30 miles, $1.55 per 1,000; 45 miles, $2 per 1,000; and 50 miles, $1.50 per 1,000. The first two are rather high and the last is very reasonable. Equipment is furnished by the carriers in all three instances.

Maintenance.—The maintenance of a logging railroad is divided into maintenance of rolling stock and maintenance of way. The upkeep of equipment begins with car inspection. While each trainload of logs is being unloaded at the mill the cars are inspected. Small repairs are made immediately, and cars in bad order are switched to the car shop. For a double-band mill the usual inspection crew consists of two men who work between times in the car shop. Where the number of cars is larger than common, or repairs are extra heavy, a third man is required in the car shop. The upkeep of trucks appears to be more than the cost of repairing flats.

Repairs to locomotives and ironwork are made in the blacksmith and machine shops maintained at the mill. For a double-band operation, the common crew in the blacksmith shop is two men, and the machine shop crew is three or four men. In addition to repairs on railway equipment, the machine shop handles both sawmill and heavy donkey repairs. The locomotives are usually brought into the shop in winter and more or less thoroughly overhauled. The cost of maintaining railway equipment depends upon the efficiency of the equipment and the length and severity of the haul. Under ordinary conditions it may be said to average from 15 to 25 cents per 1,000.

The principal part of maintenance of way is the labor of section crews. The customary crew consists of a foreman and four workmen at a daily cost of $13.50. Usually such a crew can keep from 7 to 10 miles of track in satisfactory order. Two crews are required to keep up a 14-mile line; with a daily output of 160,000 the cost is 17 cents per 1,000 and with an output of 220,000 it is 12 cents per 1,000. With the exception of a small expenditure for tools and rail fastenings, the rest of the cost of track maintenance is for tie replacement. Fir ties used on spurs last three or four years and can be lifted and relaid three times. Where they are left in place the customary sawed fir ties must be entirely replaced in five or six years. Cedar ties last considerably longer.

INCLINES AND LOG HOISTS.

Inclined tracks for lowering or hoisting logs are becoming an important engineering feature in connection with logging railroads. At points where the country rises rapidly and it is necessary for the continuation of the logging railroad to be at a considerably higher level, an incline will satisfactorily reach the upper level and obviate the construction of switchbacks or detours. Timber may often be opened up by an incline where the cost of a continuous logging railroad would be prohibitive. Furthermore, it usually costs less to operate an incline than several miles of heavy-grade railroad. Frequently inclines can be used advantageously for hoisting logs out of coves or pockets below the level of the main track.

Existing inclines have proved that their use may be extended and that no engineering conditions are likely to be met with in construction which will prove insurmountable. A common type is one in use in the central Sierras for lowering logs to the main line from a short narrow-gauge line higher up the mountain. The total length is 4,770 feet and the total descent is 840 feet. Thus the average grade is 18 per cent, with a maximum of 35 per cent and a minimum of 14 per cent. The line is a tangent for 3,600 feet, but there are two short 5° curves near the bottom. The track is 36-inch gauge with 40-pound rails, and narrow-gauge ties spaced about 10 or 12 per rail. It is well ballasted with dirt, and apparently no other provision is made to prevent the track creeping downhill. Both the initial cost of construction and the maintenance of way are less than for an equal length of railroad, because no provision need be made for the pounding action of a locomotive. The lowering equipment consists of a 10 by 12 inch hoisting engine connected with a steel drum about the same size of that on a large roading engine. A wheel about 6 feet in diameter is attached to the drum for braking. The cable used is ordinary 1-inch wire logging rope. Two skeleton log cars are lowered at one time, each with a load of 3,000 feet board measure. The average time of a trip is from 20 to 30 minutes. The loaded cars come down by gravity, controlled by the brake, and when unloaded are hauled up by the engine.

The largest incline in use in this region is one about 8,000 feet in length, which has a fall of 3,100 feet, or approximately 45 per cent. The grade is very uneven, however, varying between a maximum of 78 per cent and a minimum of 10 per cent. The track is standard gauge and is well ballasted. The upper half is double track and the lower half single track. Including gravity switching tracks at top and bottom and a 14 by 14 inch lowering engine, the total cost was approximately $100,000. There are three trestles and one bridge with a center span of 76 feet. Except for the passing switch the track is perfectly straight.

The method of operation is to lower a loaded car and hoist an empty one simultaneously. A $1\frac{1}{2}$-inch cable is used, which is supported by steel sheaves. Because of the configuration of the slope, at three points these sheaves are suspended above the track to hold the cable down. The cars used are 80,000 pounds capacity 40-foot flats, with a bulkhead on the front end. The average load per car is about 6,000 feet, weighing approximately 24 tons. One car can be lowered every 10 minutes, though the customary working speed is about four or five cars per hour.

The loads and empty cars are handled at each end by gravity switches without locomotive switching except for setting in and taking out the loaded and empty trains. Oil is used as fuel in the hoisting engine. The cable is used for one season and then taken to the woods and used as a yarding line.

Log hoists may be spurs built down into coves at a grade of from 10 to 20 per cent where otherwise a chute would be required. An extra logging donkey is ordinarily employed to let an empty car down and haul it up again after it is loaded. Another type of log hoist is one where the loaded cars are hauled up from one section of the logging road to another. One such hoist located in the southern Sierras is 2,200 feet long, with an average grade of 30 per cent and a maximum grade of 40 per cent. The track is narrow gauge with 35-pound rails and is constructed and ballasted much the same as an ordinary logging railroad. It is straight except for one 9° curve. The engineer in charge states that if there is more than one curve, they must be in the same direction. A hoisting engine is employed to haul the logs up this incline on skeleton frame cars, one or two cars at a time. The cable used is a $1\frac{1}{8}$-inch wire rope.

UNLOADING.

Unloading from horse trucks is usually done by hand with peavies, otherwise the general method of unloading logs at the mill pond is the following throughout the region. An unloading track is constructed along the mill pond with the outer rail raised to give the cars a slant toward the pond. Ordinarily a sloping deck is constructed from this track out over the edge of the pond. After the binding chains are loosened, a cable terminating in a hook is used to roll the logs from the car to the log deck. Since the pull must be toward the pond and there can be no obstruction between the car and the pond, the methods of operating and supporting this cable are varied. One method is to have a stationary boom built over the track from the land side. The cable passes through a block on the end of this boom and is operated by a small steam winch furnished with steam from the sawmill boilers. As each car is unloaded the train is shifted ahead by the locomotive or by gravity.

Another system is to place the steam winch with its own boiler upon a cribwork in the pond. The block may be attached to an overhead cable parallel to the track or the cable may be used without any supporting block. The third system is to have a special unloading machine which shifts itself along a second track on the land side of the unloading spur. No shifting of the train being unloaded is necessary. This unloader consists of a boiler and winch mounted upon a car. It may have a steel boom extending out over the loaded cars, or a block may be slung to the log deck in front of each car unloaded.

In some instances the train crew does the unloading. The fireman operates the winch, the conductor and brakeman unbind the loads and handle the unloading hook, and the engineer shifts the train. In such cases it is difficult to separate the cost of unloading from the cost of railroading. Upon one operation where the unloading is done in this manner, one pond man handles the unloading hook. A train of 55,000 is switched in and unloaded in about 40 minutes, the actual unloading requiring 30 minutes. With ample allowance for maintenance of winch and cable the cost of this unloading is $0.025 per 1,000. Another way is to have the unloading crew engage in pond work, such as sorting logs and raising sinkers, when not required for unloading. In such cases the cost of pond work and unloading is usually kept together. Upon certain large operations where self-moving unloading machines are used the practice is to have a separate unloading crew. In one case this crew consists of 1 winchman, 2 unloaders, and 1 man shoveling bark off the deck. This crew unloads 280,000 daily at a labor cost of $11, or about 4 cents per 1,000. The usual cost of unloading is from 2 to 4 cents per 1,000.

WOODS SUPERVISION.

The field supervision of logging is a very important item and may make the success or failure of a lumbering operation. Sawmilling can be pretty well standardized, but the logging of each tract must be planned on the ground, and in this planning is the chance either to cut or swell costs. Not only is the work planned for each particular area but the operations for the whole tract must be laid out long in advance. This calls for competent woods superintendents and logging engineers who are qualified to plan the layout of the railroad and logging, as well as to supervise the work.

In addition to the logging superintendent, woods supervision includes the camp foreman, timekeepers, night watchman, and chore

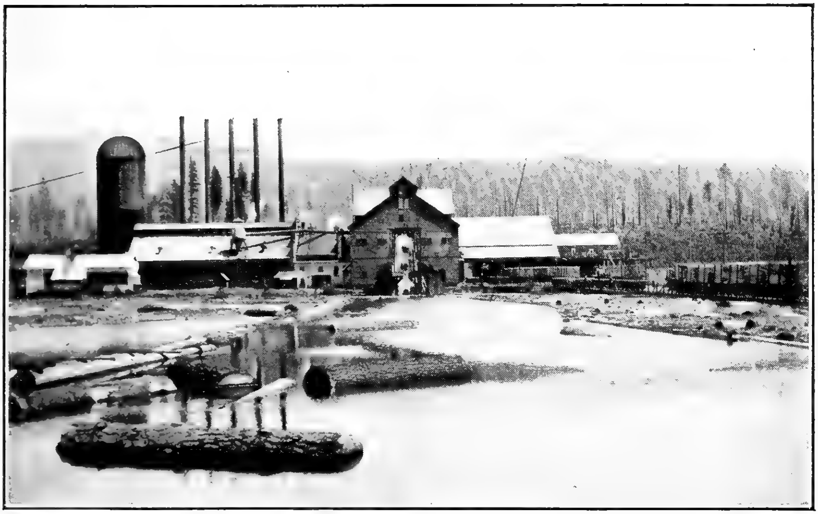


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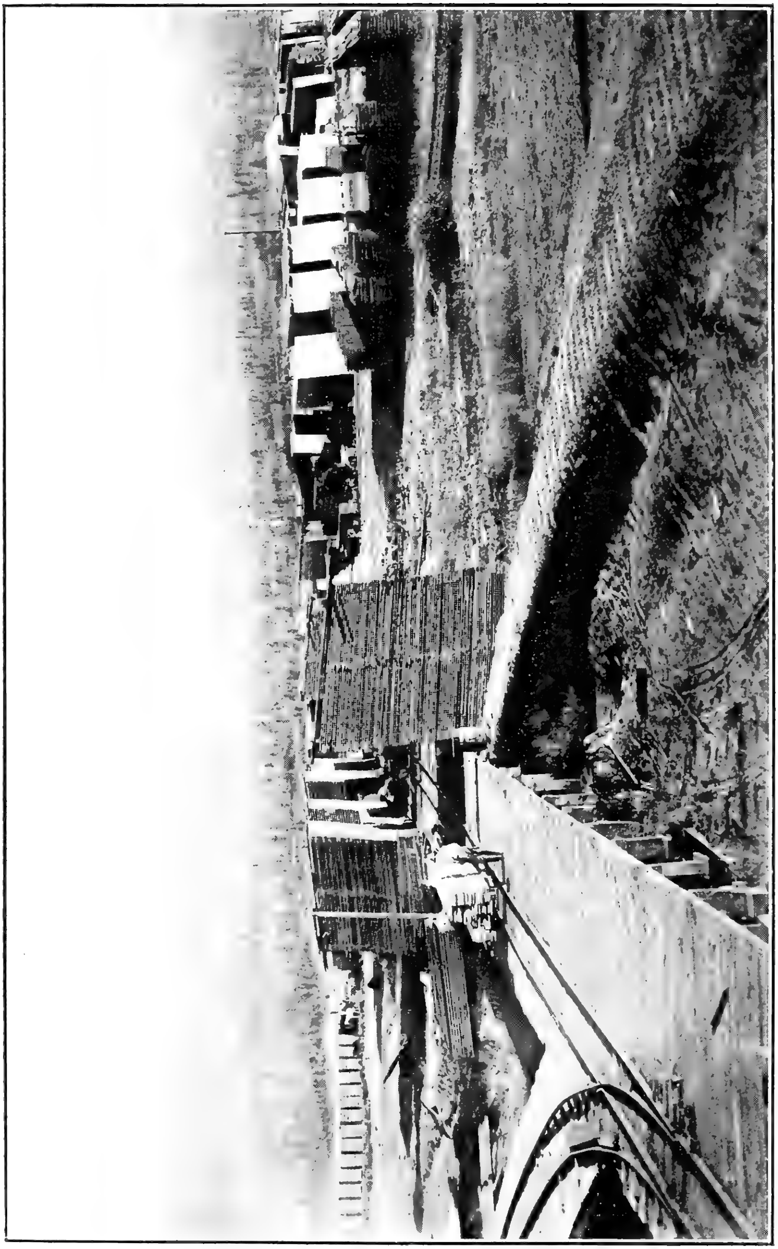
FIG. 1.—LOG POND AND LARGE DOUBLE-BAND SAWMILL AT A REPRESENTATIVE CALIFORNIA PINE LUMBERING OPERATION.

F-06316

FIG. 2.—TYPICAL SMALL CALIFORNIA SINGLE-BAND MILL. LOGS SUPPLIED BY TRUCK LOGGING.



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LUMBER YARD AT A SMALL SINGLE-BAND MILL SAWING CALIFORNIA PINE.

boys. One operation, with work divided into two camps and a daily output of 240,000, has the following force: One superintendent at $3,500 per annum, two camp bosses at $200 per month, 2 timekeepers at $70 per month, 2 watchmen at $40 per month. The daily cost, including board, is $46.50, which is equivalent to 19 cents per 1,000. A representative operation of 150,000 daily, with its work divided into two camps, has the following force: One superintendent at $3,000 per year, 1 camp boss at $150 per month, 1 camp boss at $125 per month, 1 timekeeper at $70 per month, and 2 watchmen at $40 per month. The daily cost, including board, is $34.60, which is equivalent to 23 cents per 1,000.

Another operation, with its work divided into three camps and a daily output of 500,000, has the following force: One superintendent at $4,000 per annum, 1 camp boss at $1,900 per annum, 2 camp bosses at $1,445 per annum, 3 timekeepers at $70 per month, 3 scalers at $75 per month, 4 watchmen at $40 per month, and 3 chore boys at $40 per month. The daily cost, including board, is $114.70, which is equivalent to 23 cents per 1,000. Calculated in the same manner, the cost for one representative operation, turning out 225,000 daily, is 23 cents and for another operation, turning out 160,000 daily, is 21 cents per 1,000. These figures should be increased by from 3 to 4 cents per 1,000 for work done by the railroad engineer not chargeable to construction, and other like expenses. Thus, the cost of woods supervision for large logging operations in California pine timber ranges from 22 to 27 cents per 1,000. On small horse-logging jobs the cost is generally the salary of a woods foreman or part of the time of the operator.

PART III. MANUFACTURE.

MILL POND.

Practically all sawmills in this region with a daily capacity of over 20,000 have log ponds. A few circular mills of 35,000 capacity or less do not have ponds, because of the impossibility of getting sufficient water at a reasonable cost. Mill ponds are almost indispensable for larger operations. They provide a cheap method of storing logs ahead against possible interruptions of logging operations or for extension of the milling season in the fall. In addition, they furnish the most economical means of delivering a continuous supply of logs from the railroad to the mill deck. Logs can be sorted as desired and a continuous run may be made of any species or grade. Immersion of logs in ponds tends to wash off dirt and gravel accumulated during logging and to leach out pitch and sap.

Ponds may be secured at mill sites by utilizing natural lakes or by damming small creeks or ravines. Where the mill site is on a flat, the pond is usually constructed by excavating the center and building earth dykes on the low sides. In some instances a ditch must be constructed for supplying water.

For circular mills cutting from 30,000 to 40,000 daily, the usual size of the pond is from one-half to one acre. For single-band mills where storage is not an item, the ponds vary from 1 to 4 acres. The size of ponds at double-band mills depends upon the possibilities of each site and the desire of the operator to store logs for a run of a month or more in the fall. Such ponds range from 4 to 14 acres. The usual capacity of a pond, excluding sinkers, is from two-thirds to three-fourths of a million feet of logs per surface acre. Where necessary, logs may be piled in a pond with an overhead trolley, thus about trebling the capacity. The cost is, however, very large.

The work upon a log pond may begin with unloading the cars, and includes sorting, raising sinkers, and delivering logs to the haul-up. In the yellow pine of the eastern Sierras sinkers are practically unknown, and the unloading is customarily done by the train crew. The pond crew, therefore, consists of one man for a single-band mill and two men for a double-band mill. One man is stationed at the lower end of the log slip to pole the logs into position for the hoisting chain. The other man poles the logs to within reach of the first and does sorting and general pond work. For a daily output of 120,000 the cost is about 5 cents per 1,000, which may be considered the low figure for such work in good-sized plants.

Since both sugar-pine and white-fir butt logs sink on being placed in the water, provision must be made for raising sinkers from ponds where these two species are logged. The simplest scheme is one used at a double-band mill with a small pond. The log cars are unloaded by a stationary overhead boom at a point very near the log slip. A swinging boom with a steam winch and cable is located on a cribwork in the pond. After each train is unloaded, the sinkers are picked up by tongs and swung around by the boom to within reach of the pikeman at the log slip. The crew consists of two pondmen delivering logs to the slip, one man in a flatboat attaching tongs to sinkers, and one winchman. One-third of the time of the winchman is devoted to unloading. The night crew contains only the two pondmen. The total daily cost is therefore $17, which, distributed over 250,000 feet, is 7 cents per 1,000.

At another operation, with a large number of sinkers, the cost of pond work is still greater. The pond crew does the unloading, using a winch located on a cribwork in the pond. The entire crew, except one man, works at unloading, and the average time required for an 18-car train is 20 minutes. The unloading is done at a point some distance from the log slip. When not unloading, the crew is at work raising sinkers, sorting logs, and shifting logs to the mill end of the pond. The crew consists of eight men, one of whom poles logs to the jack-works. The monthly labor cost is about $630, or 11 cents per 1,000, of which about 3 cents is chargeable to unloading. At one other large pond, where the logs are unloaded on the opposite side of the pond from the mill, the cost of picking up sinkers and storing logs is calculated for a season's run at 5 cents per 1,000, and delivering to the log slip at 4 cents per 1,000.

SAWMILLS.

Strictly speaking, the work in a sawmill is confined to sawing, which includes all activities from the removal of the logs from the pond to the delivery of rough lumber for sorting at the rear of the mill. Sorting lumber is in the transition zone between sawmill and yard. For convenience it will be considered as part of the milling operation, together with the sawing.

So far, the practice in this region is to construct the sawmill as close as possible to the timber. Small mills are almost invariably located in the lower part of the logging unit. When the unit is cut out the mill can then be moved to a new site. For large mills the site must be accessible to enough timber for a run of sufficient length to warrant the mill investment, say, from 15 to 25 years. In addition to accessibility from the logging operations, there are several other factors which affect the practicability of any site. There must be space for a log pond and a sufficient water supply. There must also be room for the sawmill, the sawmill camp, and the lumber yard. Further, the climate should be suited to air drying of lumber, and there should be transportation facilities for the lumber.

Lack of cheap water or railroad transportation for logs has made it advisable to place large mills on the nearest permanent site to the logging operations.

Most mills in the Sierras are a long distance from trunk-line railroads, and a lumber railroad or flume is necessary. The drying yards and finishing plants are commonly located at the lower terminals of these railroads or flumes, because drying and handling conditions are better there. The location of a sawmill in the valley or in a fair-sized town gives an advantage in the disposal of by-products which would not otherwise be utilized. However, under present conditions this advantage is not considered by operators as of sufficient weight to offset the necessity of transporting logs for considerable distances. As mill utilization improves in the future, this condition may change and the location of mills nearer centers of population be found profitable in many instances.

The present close connection between sawmills and logging operations results in joint ownership and management of the two throughout the region. Thus, the size of a mill is closely related to the extent of the logging operations, and both are governed by the investment in transportation facilities. The sawmills in operation vary in size from small portable rotary mills to large double-band mills with gang saws. In the description which follows, the various types of commercial sawmills are taken up in order, the smallest first. The improvements, equipment, sawing, and approximate cost of sawmilling are outlined for each. The descriptions of equipment and operation are given in greatest detail for large mills. All figures regarding outputs and costs are based on mill tally instead of log scale.

SMALL CIRCULAR MILLS.

Practically all the small mills supplying local trade, including the few water-power mills, are circular mills. There are no sash saws used so far as is known. Some of these small mills have an output as low as 10,000 feet board measure daily. The standard output for mills operating for a steady local demand or entering outside markets in a small way is from 20,000 to 25,000 daily.

These mills may either have a log landing or a small pond. Usually a chute and cable are employed for hauling the logs into the mill. Inside the mill the logs are turned on the deck and carriage by an overhead cable turner. The carriage is hand set and has either a rack and pinion or a cable drive. The saws are inserted tooth circular, there being a lower and an overhead saw on account of the large size of the logs. A series of dead rolls extends from the saw frame to the rear of the mill. Generally a small circular gang edger, with three saws, is located to the rear of the main saw. Two cut-off saws for trimming are located along the series of rolls. Some mills may have a light two-saw adjustable trimmer.

The power plant commonly consists of one engine of from 65 to 75 horsepower and a single boiler of about the same capacity. The mill is ordinarily inclosed in a frame building with a board roof. The building need have but one story. The engine and boiler are usually placed together in a lean-to adjoining the main building. The cost of such a plant complete, without yard and pond, is ordinarily about $9,000 or $10,000. In most cases, though, the latter figure will include the yard, pond, and other improvements.

The mill crew consists of the following men: One man on log hoist, 1 dogger, 1 setter, 1 sawyer, 1 offbearer, 1 edgerman, 2 cut-off men, 1 slabman, 1 sawdust man, 1 engineer, 1 foreman, and 1 night watch.

The daily labor cost for this crew is approximately $42.50. Prorating this amount over a daily average of 24,000 gives a labor sawing cost of $1.77 per 1,000. Since a considerable part of the upkeep of the mill is included in the above daily wages, there is no very definite information available relating to maintenance and supply charges.

These charges are judged, however, to be from 25 to 40 cents per 1,000 in addition to the above labor cost. The cost of sawing is thus from $2 to $2.15 per 1,000.

At mills of this size the grading and sorting is not so intensive as at large mills. The lumber is commonly partially sorted as it is loaded upon yard cars by two men, one of whom does the grading. The daily wages for this crew are about $6.50, or 27 cents per 1,000. Thus the cost of sawing and loading on cars ready for yard delivery is commonly from $2.25 to $2.50 per 1,000. Some mills efficiently managed do it for $2 per 1,000; others require $2 per 1,000 for sawing without maintenance.

LARGE CIRCULAR MILLS.

The large circular mills are commonly single mills owned by small operators. They are well adapted to logging chances not large enough for the investment involved in a band mill. For larger chances they generally can not compete with band mills on account of greater sawing cost and greater waste in sawing. Practically all the double mills started with circular saws have been changed into band mills.

Large circular mills are usually built to cut from 30,000 to 45,000 feet of lumber in a 10-hour day. When they are working well during the middle of the summer season the average output is generally about 40,000 or 41,000 per day. However, the output at both ends of the season is not quite so large, and a fair seasonal average is about 38,000 daily. The increase in output over that of the small circular mills is due to greater power and heavier and more efficient equipment.

A representative mill of this capacity is usually equipped with a chute or a log car operated by a cable and a single-geared log jacker for hoisting logs into the mill. The log deck has a log stop and loader, a steam nigger, and an overhead turner. The carriage may have either two or three head blocks and be either steam or cable feed. The set works are usually operated by hand. The saws are circular and two in number, one being placed directly over the other. The diameter of the lower saw when new is usually 58 inches. Some plants have inserted-tooth saws, but most operators prefer solid-tooth saws because of the smaller kerf. A filer must be added to the crew when solid-tooth saws are used.

Beginning at the saw frame, a series of dead rolls extends to the rear of the mill. Beside these rolls is located a gang edger, ordinarily about 52 inches wide, with four saws. The trimmer is located at one side still farther toward the rear of the mill. It may be of the gang type with seven saws or of the adjustable type with two or three saws sliding on a shaft. Some mills of this type which have a market for slab wood are also equipped with a three-saw slasher.

The power plant usually consists of an engine and two boilers. The engine is frequently underneath the mill and the boilers in a separate boiler house. The mill floor is commonly raised from the ground in order to make room underneath for shafts, belting, and conveyors. The building is frame with a board roof. A conveyor is installed for carrying out sawdust and a light track built to an outside burner for slabs. The cost of the equipment in such a plant is about $10,000. The cost of delivery, installation, and construction of the building brings the cost of the completed plant up to $15,000 or $17,000, exclusive of pond and yard.

In a representative mill of this type two men are required to operate the log jacker, do the scaling, and roll the logs down on the deck. The logs are turned on the carriage by the steam nigger; and two men, a setter and a dogger, handle the setworks and the dogs on the carriage. The sawyer is located at the saw and the offbearer places the boards and slabs on the rolls as they are sawed from the log. The pointer transfers boards from the rolls to the edger table and the edgerman manipulates the edger. One man is stationed at the rear of the edger and two men manage the trimmer. The slabs are loaded on cars and delivered to the fuel piles or slab fire by two men. The remainder of the crew consists of a foreman, an engineer, a fireman, a filer, a millwright, and a night watchman. The total crew contains 19 men, and the daily cost is about $63.20. Based upon an average daily output of 38,000, the direct cost of sawing is $1.66 per 1,000. With a daily average of 40,000 the direct cost is $1.58 per 1,000. The labor cost of maintenance is largely covered by the wages of the sawyer, engineer, and millwright. The additional cost for supplies and overhauling is judged to be from 25 to 40 cents per 1,000. Thus the cost of sawing is from $1.90 to $2.10 per 1,000 feet.

There are two common methods of loading lumber for yard delivery at these mills. One is to load the boards on small cars directly behind the trimmer; the other is to allow the lumber to pass upon a sorting table behind the trimmer, from which table it is loaded on various lumber cars or trucks. The latter method allows a better separation of the different grades. The crew is the same in each instance, a grader and two sorters. The daily labor cost is $9.25, or the equivalent of 24 cents per 1,000 for a daily output of 38,000. Thus the average cost of sawing and sorting in mills of this class is from $2.10 to $2.40 per 1,000, depending upon the cost of labor and material and the class of lumber manufactured.

Circular mills are frequently intermittent in operation and thus incur costs while idle. Crews are often less efficient than in larger mills, and the mill equipment and yard facilities generally are not such as to obtain the best quality of lumber from the logs.

SINGLE-BAND MILLS.

The principal advantages of a band mill are the small saw kerf and high speed in sawing. The investment is larger than for a circular mill and the daily output must be greater. This calls for heavier and better equipment all through the mill.

Single-band mills are well adapted to medium-sized logging chances and have many advantages over both smaller and larger mills. The initial investment is not too great for an operator of moderate means; and the operation lends itself peculiarly well to management by one man. Thus, in many instances it is the most desirable mill for operating in National Forest timber. Because of certain disadvantages in operation and upkeep, the sawing cost is frequently a little higher than for a double-band mill. Where the output of a single-band mill in 10 hours will not warrant the required investment in logging facilities and stumpage, it is often better to work a day and a night shift than to construct a double-band mill. The disadvantage of working double shift is that little time is left for mill inspection and repairs.

Although similar in type, single-band mills throughout the region vary in details and thoroughness of construction, according to the length of time they are to be used and whether they are to be operated for one or two shifts daily. The initial cost varies from $35,000 to $75,000, exclusive of pond and yard. The 10-hour output likewise ranges from 50,000 to 65,000. The output for a mill operating double shift is from 110,000 to 120,000 per day.

The equipment varies in the same way as the construction; that is, heavier equipment is used in the mills intended for operating double shifts or producing the maximum daily output. The sawing equipment of a representative mill consists of the following articles:

1 log jacker.
1 log kicker.
1 log stop and loader.
1 steam log turner.
1 8-foot or 9-foot band mill, either right or left.
1 carriage, with either two or three head-blocks.
Steam or power set works for carriage.
Steam or cable feed works for carriage.
1 series live rolls.
1 60-inch gang edger.
1 lumber transfer to trimmer.
1 slash transfer.
1 overhead slasher.
1 gang trimmer.
1 lumber-sorting transfer.
1 chain refuse conveyor.
Filing room, equipped for filing band and circular saws.

The mill building is commonly of two-story frame construction, 35 or 40 feet in width by 120 feet in length. The roof is often made of corrugated iron instead of shingles or boards. The boilers are placed in an adjoining boiler house, which may be of wood, corrugated iron, or brick, depending upon the permanence of the mill. The engine room is usually underneath the mill floor. A satisfactory power plant consists of a 16 by 36 inch engine and two 60-inch by 16-foot boilers, the aggregate development being from 250 to 300 horsepower.

The crew of a representative single-band mill is made up of the following men: One man scaling and operating log jacker, 1 man on log deck, 1 sawyer, 1 setter, 1 dogger, 1 offbearer, 1 pointer, 1 edgerman, 2 men at rear edger table, 1 man tending cut-off and slasher, 2 men at trimmer, 1 slab and burner man, 1 foreman, 1 filer, 1 millwright and oiler, 1 engineer, 1 fireman, 1 laborer clearing up bark and refuse, and 1 watchman.

The daily cost of this crew is approximately $75. With a daily output of 60,000 the direct cost of sawing is $1.25 per 1,000. The average cost of maintenance, including supplies and repairs, is approximately 50 cents per 1,000. This is an average for the normal life of a mill, the repairs being less during the first few years. Thus the average sawing cost is about $1.75 per 1,000, varying normally from $1.65 to $1.85 per 1,000. Some single-band mills by efficient arrangement and more elaborate equipment cut down the above crew without reducing the output, until the cost of sawing is as low as for a double-band mill.

All single-band mills use a table with chain conveyor for grading and sorting the lumber after it leaves the trimmer. The standard crew consists of one grader and four sorters, and the daily pay roll is about $13.75. The cost for a daily production of 60,000 is therefore about 23 cents per 1,000. Thus the total cost of sawing and sorting normally ranges from $1.90 to $2.10 per 1,000.

DOUBLE-BAND MILLS.

Double-band mills produce the bulk of the lumber output of the region, and the description of their equipment and sawing operations is given below in detail. The typical mill with twin band saws is frequently increased by the addition of a resaw or a gang saw. In some mills one of the band saws is of the so-called pony type, and one scheme of mill layout involves a single band and a gang. The standard type is accordingly described first, after which the various modifications are mentioned. A rough plan of the layout of a double-band mill is given on page 73. No two mills are designed exactly alike, and the plan given is not advanced as a model but is simply intended to show the general type of sugar and yellow pine mills and to assist in a clearer understanding of the text.

The first step in the operation is the removal of the logs from the pond. Since the sawing floor is commonly elevated, it is generally necessary to hoist the logs some distance. This is accomplished in two ways; by the use of a steel car drawn up on a track by a cable, or by hauling the logs one at a time up a log slip by an endless sprocket chain. The latter method is the better, especially when the logs are to be hoisted a considerable distance. Less power is required for the other method, however.

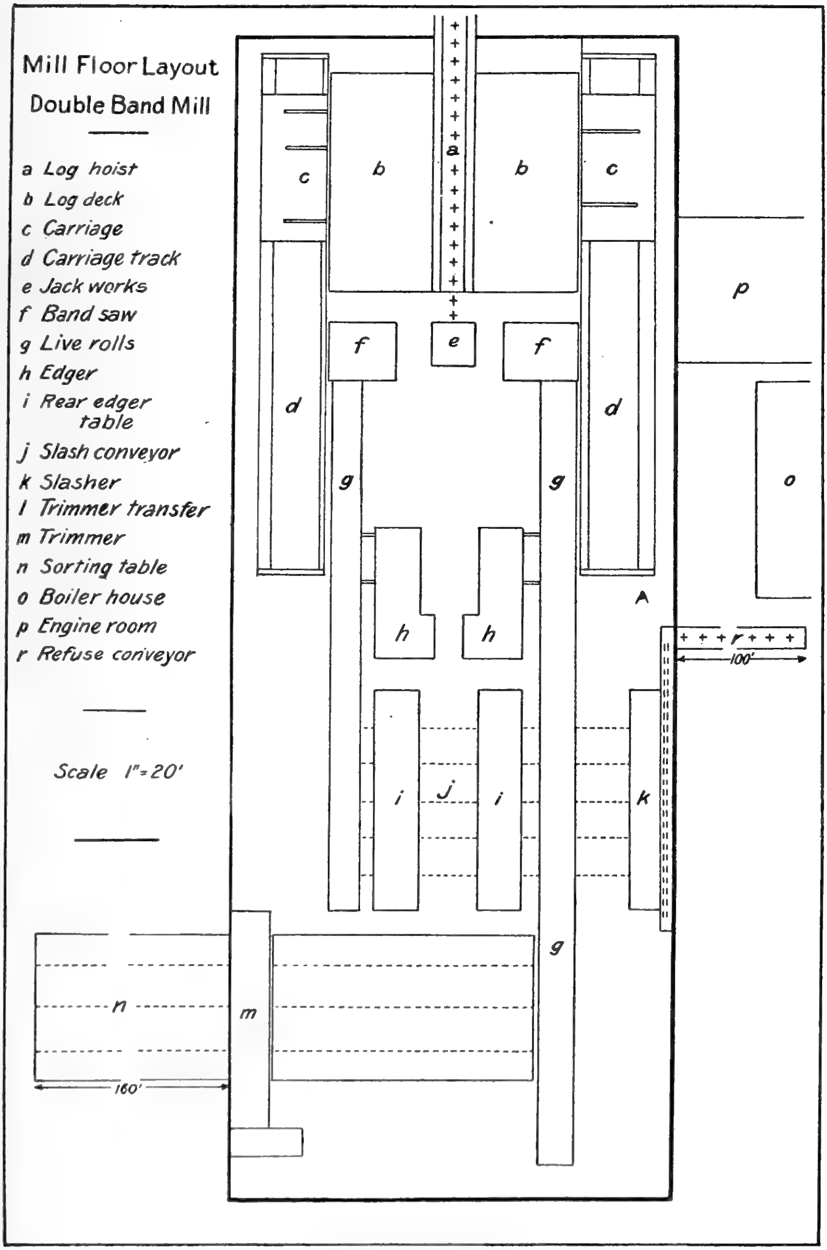

FIG. 2.—Mill floor layout.

The log hoist enters about the center of the front end of the mill building. A log deck slopes either way from it toward the sides of the mill; one for the left-hand and the other for the right-hand saw. Each log deck is about 30 feet long and 12 or 14 feet wide. One man is stationed at the head of the log hoist to operate the jack works and scale the logs. Where a log slip is used he also operates the steam log kicker, an appliance that shoves the logs out of the slip onto one or the other of the decks.

One side of the mill, that with the smaller saw, is commonly selected for sawing the smaller logs. Thus the small logs are kicked out on the deck on that side, which for the sake of convenience may be considered in this description as the right-hand. Usually two men are kept on the log decks to clean the logs and remove all dirt, gravel, etc., from the bark. As the logs roll down the decks they are stopped and held until ready for loading on the carriage by the steam log stop and loader. The actual loading and turning of logs on the carriage is done by a steam log turner on the left-hand deck and a steam nigger on the right-hand, the latter having the more rapid action and therefore being better adapted to handling small logs.

The left-hand carriage is equipped for handling large logs and has two headblocks about 10 feet apart. It is usually propelled by steam (shotgun) feed. The other carriage is usually lighter and equipped with a faster feed, which may be either steam or a cable operated by a twin engine. The right-hand carriage often has three headblocks, spaced 10 and 5 feet apart. Both carriages usually have the same kind of set works, which may be either rope drive or steam, the former preferred. Three men are required on each carriage, the setter to operate the set works and two doggers to set the dogs at each end of the log.

The sawyer is stationed directly between the log deck and the saw. He exercises general supervision over the sawing of the logs, instructing the setter as to the material to be cut from each. He operates with one hand the lever which controls the movements of the carriage, and with the other the lever which directs the work of the steam nigger or log turner. He controls the log stop and loader by a foot lever. One sawyer is required for each band saw.

Band mills consist of an endless saw revolving upon an upper and a lower wheel. The wheels are usually 8 feet in diameter for the smaller saw and 9 feet for the larger, the combination of 9 and 10 foot mills occurring in but few instances. The sawing is done at a point between the two wheels. The bands used in this region have but one cutting edge, thus but one board is removed at each forward and backward movement of the carriage past the saw. The saws commonly used in California pine are 14 gauge and are swaged to cut a kerf of five-thirty-seconds inch or scant three-sixteenths inch. The width may be either 12 or 14 inches. The length of a saw for a 9-foot band is 56 feet, and for an 8-foot band the length is 45 feet. The cost f. o. b. San Francisco is $2.25 per foot for 12-inch widths, and $3.15 per foot for 14-inch.

As the slabs and boards are sawed from the log they fall upon live rolls, consisting of iron cylinders 1 foot in diameter and 2½ or 3 feet in length, spaced 4 feet apart in two parallel series extending from each band saw to the trimmer conveyor in the rear of the mill. The rolls are rotated continuously in the direction of the rear of the mill by means of shafting and gears. An off-bearer stands behind each saw for the purpose of seeing that the boards and slabs fall on the rolls free of the saw.

The boards pass down the live rolls until they reach the edgers, where an automatic transfer removes them to the edger table. An edger is provided for each band saw. The usual type is a 60-inch gang with four or five circular saws. Two men are required at each edger, a pointer and an edgerman. The boards are fed through the edger, the saws having first been adjusted to cut off the edgings and saw the boards into the widths desired.

From the edgers the lumber and edgings pass to a double series of live rolls, about 6 feet wide and 30 feet in length, termed rear edger tables. Underneath these tables there are a number of conveyor chains working toward the side of the mill where the slash saws are located. Two or three men are stationed at the rear edger tables for shoving edgings off onto the slasher conveyor. One of these men also tends the slasher. Slabs do not go through the edgers but pass directly down the rolls and are thrown off on the slasher conveyor by the same three men. The slasher consists of from five to seven circular saws set either 3 or 4 feet apart on a shaft. The slabs and edgings pass under these saws and are cut in lengths for cordwood or lath bolts.

The rear edger tables deliver the lumber to the trimmer transfer, where another chain conveyor moves the boards to the trimmer. The trimmer consists of 10 or 11 circular saws, mounted in a row. It may be either of the underneath or overhead type and be either hand or pneumatic lift. Its function is to trim off the ends of the boards to standard lengths. After going through the trimmer the boards pass to the sorting table, where the grading and sorting is done. The crew at the trimmer consists of the trimmerman, who adjusts the saws, and two men who arrange the boards on the trimmer table. A third man is often necessary on the trimmer conveyor.

A short conveyor is located behind the slasher for the purpose of transporting the slabs and edgings to the main conveyor and refuse burner. Lath bolts and wood are commonly picked out of this conveyor, when utilized. On the lower floor of the mill is located all the machinery for transmission of power to the sawing equipment on the mill floor. There are also various conveyors for transporting bark, pieces of slabs, and trimmings to the main refuse conveyor. A special conveyor delivers the sawdust to the boiler room for fuel.

The standard equipment for a double-band mill is six 60 inch by 16 foot boilers, capable of operation at 150 pounds steam pressure. One of these furnishes steam for the various steam appliances and the other five supply the engines. One or two engines capable of producing an aggregate of from 500 to 650 horsepower are necessary. The usual plant consists of two engines, one with about 200 horsepower and the other about 400 horsepower, or there may be one large engine of from 450 to 500 horsepower and a small one of from 100 to 150 horsepower. The engine room also contains a generator for electric light and one or more steam pumps.

A very important part of the work in a band mill is the filing of the saws. Expert labor and special equipment are required. The filing room is usually located in the garret above the mill floor. Unless accidents occur, four saws are used daily on each band mill. Usually a stock of four or five saws is kept on hand for each band. The usual filing room equipment consists of one band saw gumming and filing machine, a similar machine for circular saws, one roller for band saws, an anvil, forge, and various hand swages.

The standard crew of a double-band mill contains, in addition to the men mentioned above, an engineer and two firemen, a millwright, an oiler, one laborer tending refuse conveyor and burner, and one laborer clearing refuse on mill floor. When the mill is operating two shifts the entire crew given above is duplicated at night. The mill superintendent, two filers, and a laborer clearing refuse on the machinery floor are on duty only during the day shift. A watchman is required at night. The common practice is to work two 10-hour shifts, one during the day and one at night. When some mills operating only in the day shift wish to increase slightly the output, an extra shift of 2½ hours is worked in the evening by the day crew. This procedure is termed working a time and a quarter. If this is continued long the crew is liable to become overworked and the production suffer. This is particularly true with regard to the band sawyers, upon whose skill and watchfulness the correct manufacture of each log largely depends.

The usual crew of a double-band mill consists of 36 men for a single shift and 68 men for two shifts. The amount sawed is usually slightly greater during the day shift. The daily labor cost at a double-band mill operating two shifts is approximately $265, which, prorated over a daily output of 240,000, is about $1.10 per 1,000 for sawing. Information available indicates that the direct cost of sawing at double-band mills in this region normally varies from $1.10 to $1.20 per

1,000. At one such mill the average labor cost for a recent season was $1.17 per 1,000, divided as follows:

Sawyer	$0.218	Oilers	$0.129
Edgerman	.122	Millwrights	.064
Trimmers	.097	Watchmen	.021
Refuse crew	.137	Superintendent	.047
Deckmen	.043	Miscellaneous	.044
Engineers	.082	Total	1.173
Fireman	.080		
Filers	.089		

The cost of maintaining a double-band mill after it has been in use a few years is reckoned as normally averaging about 50 cents per 1,000 feet board measure, upon the basis of the material sawed. Maintenance includes sawmill supplies and sawmill repairs. A representative division is 31 cents per 1,000 for repairs and 19 cents for supplies. The supply charge may be roughly divided into the following items:

Saws	$0.06 per 1,000
Tools	.005 per 1,000
Oil and waste	.05 per 1,000
Miscellaneous	.075 per 1,000

In a few instances double-band mills are not of the twin type described above. The two bands are placed tandem, the rear one being used as a pony mill. All logs are accordingly sawed on the first band in the usual way. Small logs are, however, cut into cants which are sawed into lumber by the second band. The carriage of the smaller band is accordingly operated at a high speed. This arrangement of the saws permits a slight decrease in the mill crew, but on the other hand the daily output is generally lowered. One large operator who has had experience with both types believes this to be the most economical type of double-band mill, if properly arranged.

The mill building for a double-band mill is at least 60 feet wide and 160 feet long. For mills of heavy construction and those equipped with a gang or a resaw the standard width is 70 feet and the length ranges up to 200 feet. There are commonly two stories with an attic for a filing room. The construction material is wood. Corrugated iron is frequently used for roofing, and sometimes for siding. A steel frame is found in but one mill, the added cost being from $25,000 to $30,000. The engine room may be located in the lower story or in a small addition to the main building. The boiler room is a separate building, usually of masonry or corrugated iron construction.

The cost of a double-band mill varies somewhat with the type of construction and length of probable operation. Large timber requires heavy equipment which costs more to purchase and install.

A long operation requires more permanent construction. The cost also varies with the location, because the expense of transporting material to some sites is a considerable item. Under normal conditions the cost of the lighter double-band mills complete, exclusive of pond and yard, is from $100,000 to $110,000. The heaviest and best constructed mills cost from $130,000 to $145,000.

One such plant recently constructed cost $145,000 complete with machinery, power plant, and buildings. The cost f. o. b. San Francisco, of the equipment contained in this plant was as follows:

Boilers, about 700 horsepower	$7,000
Engine, 650 horsepower (28 by 48 inches)	6,000
Two log kickers	1,200
Two log stops and loaders	735
Log turner	1,900
Steam nigger	550
Band mill (9-foot)	2,350
Band mill (10-foot)	2,700
Two carriages	$4,980
Two edgers	2,560
Slasher (7 saws)	550
Air lift trimmer (11 saws)	1,125
Live rolls, transfers, conveyors, chains, etc	18,350
Total	50,000

In addition to this equipment, belts, saws, piping, and other miscellaneous hardware were required at a cost of about $15,000 delivered at the site. The itemized cost of a double-band mill aggregating $100,000 is approximately as given below:

Machinery, including power plant	$40,000
Miscellaneous supplies and hardware	10,000
Lumber and timbers	$9,000
Mill foundations and boiler house	7,000
Freights and delivery	10,000
Labor in construction	24,000

A machine shop of some sort is required at every double-band mill. In it are handled heavy repairs to logging and mill equipment. The cost of a well-equipped shop is about $10,000 or $12,000. The equipment consists of 2 or 3 lathes, 1 or 2 planers, 2 drills, 1 bender, 1 steel saw, and 1 cutter and threader. A blacksmith shop is maintained in connection with the machine shop and is fitted with a trip hammer, a forge, an anvil, and a complete outfit of blacksmithing tools. A typical crew comprises 3 machinists, 1 steam fitter, 1 blacksmith, and a helper.

Two sorts of refuse burners are used. Mills located in the woods usually have an open fire with a corrugated iron or masonry shield. Those situated in towns or near extensive lumber yards have steel refuse burners with brick foundations and linings. Such a burner for a double-band mill is about 70 feet high and 20 feet in diameter, and is said to cost from $6,000 to $9,000 in place.

The average output of a double-band mill is usually about 120,000 or 125,000 in a 10-hour shift for the entire sawing season. A similar average output for two shifts is 240,000 daily. During the middle of the season when everything is running nicely these average outputs will be exceeded by from 10,000 to 30,000 per day. One firm even averages for a month or more at a time a daily output of 180,000 in a 10-hour shift. The dimensions of the material manufactured have considerable effect on the output; the more thick stock the greater the output

One method of increasing the output of a double-band mill is to add a resaw to the equipment. The mill is built somewhat wider, and the resaw is installed between the rear edger tables just aft of the edgers. The usual type of resaw is a 6-foot horizontal or vertical band. Material to be resawn is sent down the live rolls to an automatic transfer, which carries it to the feeding table of the resaw. Each plank is fed through the resaw in the direction of the front end of the mill. A third edger is placed beside the resaw for handling the resawed material. The usual mill crew is increased by 2 men feeding the resaw, 1 sawyer, 1 man at rear of resaw, 1 edgerman, and 1 man at trimmer conveyor. The average daily output is 160,000, an increase of about 35,000 because of the resaw.

A less desirable means of making a similar increase in output is the the installation of a gang saw. The gang is set upon a solid foundation midway between the band saws and the edgers. A small deck slopes from the live rolls on either side to a set of feed rolls in the center. Cants are cut from time to time by the band saws and delivered from the live rolls to the feed rolls of the gang by automatic kickers. The cants are then slowly fed through the gang by the feed rolls, thus producing a number of boards at one time. A separate series of rolls extends from the gang to the trimmer conveyor.

A gang-saw crew consists of 1 man at the feed rolls, 1 sawyer, 2 men at rear table, and 1 man on trimmer conveyor. The daily output of a double-band mill with a gang is about 160,000 feet board measure. The common type of gang saw is capable of cutting a cant 28 inches wide and 12 inches thick. The cost f. o. b. the factory is about $5,000. It produces perfectly sawed lumber, but it is impossible to saw to produce higher grades, as is done with a band saw. Thus gang saws are generally not regarded with favor in the sugar and yellow pine region where the profit is made from the upper grades. A gang saw can, however, be used to advantage upon an operation producing enough low-grade logs, suitably only for common or box lumber, to supply it all the time. Otherwise there is a tendency to run better-grade logs through it at times, which results in a loss of uppers.

A mill of an unusual type in this region, there being but two in operation, consists of a single band and a gang. The operation is in general the same as in a double-band and gang mill. The average daily output for a single shift is from 100,000 to 120,000.

Electric drive for sawmills has not been introduced as yet on an extensive scale, there being but one sugar and yellow pine mill so equipped. The power is generated in the engine room of the plant and each piece of machinery in the mill is driven by a separate motor. The intricate machinery located on the lower floor of a mill for the transmission of power is eliminated, and one portion of the mill may be shut down for brief repairs without interfering with the rest. The installation of an electric drive makes a considerable increase in the initial cost of a mill.

The majority of the mills in the region utilize a considerable portion of the waste in slabs and edgings by making laths. A lath room is located in an addition on the side of the mill building near the slasher. At a representative double-band mill where both laths and car strips are manufactured, 2 men are required to sort material out of the conveyor at the rear of the slasher. The remainder of the crew consists of 2 men at the bolter, 2 at the saw, and 2 men bundling and jointing. The mill is equipped with separate bolters, saws, and jointers for both laths and strips. Only one product is manufactured at a time. From 180 to 200 bundles are produced daily. The demand is limited and the profit small.

Many mills have a market for fuel wood cut from slabs. Various devices, such as gang cut-offs, are used to saw the slabs and slashings into stove lengths. One progressive concern takes advantage of a chance for close utilization by resawing slabs. The larger slabs are cut in 4 and 6 foot lengths with a cut-off saw and transported by a conveyor to a resaw in the nearby planing mill. This resaw is a small horizontal band. The slab sections are resawed and edged, thus making excellent box and factory material.

The grading and sorting of the lumber is done on a sorting table which commonly extends at right angles from the mill, opposite the trimmer. This sorting table is 18 or 20 feet wide and from 120 to 160 feet in length. The lumber is carried slowly toward the outer end by means of conveyor chains or cables. The grader stands at the end near the mill and marks the grade symbol on each board with a crayon. As the boards are carried along the sorting chains they are picked up by the sorters and loaded on the proper cars. The cost of grading and sorting is about 25 cents per 1,000. At a mill producing 160,000 daily the crew consists of 1 grader and 14 sorters. The daily labor cost is $38, or 24 cents per 1,000. At a mill producing 120,000 daily the crew consists of one grader and nine sorters, at a daily labor cost of $26, or 22 cents per 1,000. The total cost of sawing, grading, and sorting at double-band mills is normally between $1.85 and $1.95 per 1,000.

SAWMILL LUMBER YARDS

Under "sawmill lumber yards" is included all handling and treatment of lumber from the time it is sorted until it is loaded on cars ready for shipment to market.

Wherever conditions are favorable, it is customary to locate the drying and shipping yard at the sawmill because of greater economy. However, this is often impossible. There are two general types of yards. In one, the lumber is distributed on elevated platforms; in the other, tracks are built at ground level.

Yards at small circular mills usually have a single track extending straight out from the mill with pile bottoms on either side. Under most conditions the necessary length is about 600 feet, and about 50 pile bottoms are required. The track may be either on the ground or on a platform raised about 10 or 12 feet. The slope should be away from the mill. Ordinarily, low four-wheeled cars are used. The cost of such a yard, exclusive of the site, is estimated to be from \$600 to \$800 for a ground track and from \$1,000 to \$1,200 for a raised platform. The larger circular mills require more yard room. This is usually secured by constructing two or more parallel tracks or platforms with piles on either side. Some operators haul the lumber out with carts and have only dirt or plank roads between the piles. Although the amount of yard stock at different mills varies with market and other conditions, the yard at a large single circular mill must ordinarily provide room for from 2½ to 3 million feet of lumber. This requires from 150 to 160 pile bottoms and 2,000 feet of trams. Accordingly, the yard cost is from \$2,000 to \$3,300, the latter for elevated trams.

Single-band mills have the same general layout of yards except that more space is required. A single-band mill operating one shift daily, normally requires maximum yard room for the storage of about 5 or 6 million feet of lumber. Thus from 200 to 250 pile bottoms and about 3,000 feet of trams are necessary. The average cost is placed at from \$3,800 to \$5,000. From one-half to three-fourths of a mile of loading spur will also be required at a cost of from \$2,400 to \$3,600.

There are three kinds of yards used for double-band mills in this region. The most common is the type with raised trams or platforms. These platforms are constructed in parallel series through the yard, generally at right angles to the mill. A similar platform connects the various branches to the upper floor of the mill. The platforms are constructed at a height of from 9 to 16 feet above the ground, the normal height being about 12 feet. The floor is 12 feet wide and is built of 2-inch planks. The trams are supported by 3 by 8 inch stringers and 4 by 6 inch uprights resting on 6 by 6 inch sills. About 4,000 feet of lumber is used to build each 100 feet of length.

The cost of such platforms may be computed on the basis of a cost of \$18 per 1,000 for the lumber used in construction. If cars are to be used for distributing lumber, 16-pound rails must be laid on the trams. The cost of such track, including rails, rail fastenings, and laying, is about $22 per 100 feet.

The usual yard arrangement provides for a row of lumber piles on each side of every platform. Foundations must be constructed of timbers for each pile. They contain from 400 to 500 feet of lumber apiece; and the cost of construction, including the value of the lumber, is usually about $8 each. Enough space is left between adjacent platforms to allow room for the construction of a wagon road, yard car track, or loading spur between the two series of lumber piles.

Yard tracks are commonly 36-inch gauge with 16-pound rails, and are constructed at about the following average cost per mile:

Steel and fastenings	$1,100
Ties	500
Grading	200
Laying and surfacing	300
Total	2,100

Loading spurs are standard gauge with about 35-pound rails. The cost per mile of length is reckoned as follows:

Steel and fastenings	$2,500
Ties	1,000
Grading	500
Laying and surfacing	500
Total	4,500

A yard with a storage capacity of 12,000,000 feet, at a representative double-band mill operating one shift daily, contains about 500 pile bottoms, 7,000 feet of platforms, 7,000 feet of yard track on platforms, 1 mile of loading spurs, and 1 mile of ground yard track. The cost would be reckoned as follows:

Pile bottoms	$4,000
Platforms	5,040
Platform tracks	1,540
Yard tracks	2,100
Loading spurs	4,500
Total	17,180

The cost of a yard of the platform type at a double-band mill with an annual output of from 18 to 20 million feet of lumber is usually from $16,000 to $20,000. The cost of a yard at a mill producing from 35 to 40 million feet annually would be about twice as much.

The second kind of yard is one having the tracks located on the ground. The piles are on both sides of parallel tracks in much the same manner as with platforms. The cost, computed on the same basis as above, is about $15,000. Another yard of this same type has dirt roads between the piles, upon which the lumber is distributed by horse trucks. The cost is decreased by the elimination of yard tracks.

Water systems must be installed for the protection of all yards, at a cost in addition to the above. Yard equipment, such as cars or trucks, represents a considerable additional investment. Sheds are added to most yards for storing air and kiln dried lumber.

From the sorting table lumber is distributed to the piles by means of two-wheeled lumber trucks (buggies) or low four-wheeled cars. Steel tracks are required for the cars, but the trucks can be used on plank platforms. If the yard slopes slightly away from the mill both cars and trucks may be handled by hand labor. Where the haul is long or difficult horses may be used. Apparently one of the most economical methods at large mills is to use a small gasoline or electric locomotive.

The cost of distributing lumber ready for piling averages from 20 to 25 cents per 1,000. The cost at small mills is frequently lower than at large mills, because the distance is less. At one mill cutting 20,000 daily two men are required to push the loaded lumber cars to the yard and unload them. The daily cost is $5, which is at the rate of 25 cents per 1,000. However, one of these men devotes part of his time to wheeling out slabs, so the actual cost is less. At a representative single-band mill sawing 60,000 feet in a shift of 10 hours the lumber is distributed in the yard on cars by four men, at a cost of $11 per day, or 18 cents per 1,000. A smaller single-band mill with a daily output of 50,000 maintains a crew of four men to wheel the lumber out on trucks. The wages are $10 daily, or 20 cents per 1,000. A double-band mill located at the upper end of a flume, and having a daily output of 250,000, has a crew of 20 men distributing lumber on trucks. At a daily wage of $2.50 each the cost is $50 per day, or 20 cents per 1,000.

After the lumber is distributed the next step is piling it. The boards are laid in layers, stickers 1 or 2 inches thick being placed between the layers in order to provide circulation for air in drying. Spaces are left between the various boards in each layer for the same purpose. The piles are made with the rear end lower, and when completed are roofed to shed rain. Each pile preferably contains a single grade and boards of one length only.

Piling is ordinarily done by hand, two men working together. For high piling derrick hoists operated either by a horse or by an electric motor are used to raise the boards. A third man is required in such instances. An electric piler requiring only two men is used by one company. Piling lumber is tedious work and is a job at which best results seem to be secured by contract. In fact, so much of the piling is done by this system that contract rates may be taken as standard costs. These rates for piling up to 15 feet above the track or platform range from 35 to 40 cents per 1,000 feet board measure. At some mills the rate is 35 cents per 1,000 for ordinary piling, and 50 cents per 1,000 for piling clears, with which extra care is taken. The contract rate for piling over 15 feet above the tram is 40 cents per 1,000, upon condition that the company furnish a man and horse for the hoist. On contract work two men usually pile a little more than 20,000 feet daily, thus making very good wages. When working by the day two good men pile from 15,000 to 18,000 daily. At one single-band mill eight men pile the daily output of 60,000 at a labor cost of $20 daily, or 33 cents per 1,000. Upon the basis of the above costs the average cost of taking lumber from the mill and placing it in the piles is from 60 to 70 cents per 1,000.

When lumber is loaded from the piles directly to cars for shipment the cost is from 30 to 35 cents per 1,000, including grading. However, it is not possible to load much lumber in this manner because several different grades, which come from different piles, must be placed in one car. At one mill where the lumber is dried in the mill yard but shipped to the main line on a narrow-gauge railroad the cost of loading is about 34 cents per 1,000, including grading, and the cost of transferring to standard-gauge cars at the lower terminal is 33 cents per 1,000. Usually the lumber is taken from the pile and loaded on small yard cars. These yard cars are pushed a short distance to the loading dock where the standard-gauge cars are spotted for loading. The cost is from 20 to 25 cents for the first handling and the same for loading, plus about 10 cents per 1,000 for grading and running cars. Since some lumber is loaded by both methods in most yards, it seems proper to figure the cost of shipment of rough lumber at 50 cents per 1,000. It is customary to figure that lumber can be handled once (from piles to finishing plants, for instance) for 25 cents per 1,000.

In addition to shipment and delivery of lumber to finishing plants there is a certain amount of extra handling of lumber in the yards of all large mills. This consists in the resorting and transportation of material which has depreciated in grade, and similar work. The extent and cost of such work varies greatly.

A certain amount of supervision is necessary in any yard. At a single-band mill there is usually only a yard foreman. At a double-band mill the yard office ordinarily contains a yard foreman and a clerk, who are employed practically the year round. The cost of yard supervision is therefore about 8 or 10 cents per 1,000. There is a small additional yard cost for the maintenance of tracks and tramways. This probably does not exceed 5 cents per 1,000.

On the east slope of the Sierras the climate is so well suited to drying lumber that dry kilns are not necessary. On the west slope, however, it is the practice to run part or all of the upper grades of yellow pine through a dry kiln on account of the danger from blue stain in air drying. A kiln 20 by 100 feet has an average daily capacity of 12,000 feet. Thus at a single-band mill the usual kiln is about 20 by 75 feet or 20 by 100 feet. Under very unfavorable drying conditions such a mill may have a pair of kilns each 20 feet wide and 70 feet long. At a double-band mill, operating two shifts, the dry-kiln plant consists of two kilns each 20 by 100 feet, if drying conditions are favorable. Under less favorable conditions the plant is often double that size.

Dry kilns may be made of masonry, concrete, wood frame, or wood crib. Masonry and concrete are said to give the best satisfaction. Wood crib is rated as being superior to wood frame construction. The cost of the equipment and fittings for a kiln 20 feet wide and 100 feet long, inside measurement, is about $1,600 f. o. b. factory. With a wood crib frame the cost of a kiln of this size in place is from $3,500 to $4,000. A kiln 20 by 70 feet with wood frame costs about $2,500 in place. A kiln of the same size costs about $10,000 if the material is concrete; and $7,000 if the material is tile. The average cost of kiln drying lumber in this region is usually from 75 to 80 cents per 1,000. The cost of handling is approximately 65 cents per 1,000.

A portion of the upper grades is usually stored in sheds if it is not shipped immediately after air or kiln drying. The construction of sufficient shed room to accommodate all upper grades would undoubtedly be an economy, because such sheds, though they involve an extra handling, do much to prevent deterioration in the quality of the lumber and insure a higher return. Care with wide and thick sugar pine lumber pays especially well. All yards in this region suffer from lumber depreciation by waste or change in grades through staining, checking, etc. The amount of this depreciation varies with yard conditions and the care in handling. It is generally greater in thick lumber than in thin lumber. Yards with unfavorable climatic and meteorological conditions suffer more heavily than those with good drying conditions. Deterioration takes place in kiln drying and surfacing, as well as in air drying. Thus shipping tallies at yards differ in amount and quality from mill tallies of lumber. Little is now known of the amount of deterioration; but studies are being undertaken to determine the amount and extent of depreciation in each grade, under different seasoning conditions and methods.

Sometimes surfaced lumber is shipped from the larger mills in order to save on freight charges. Thus, in stumpage appraisals it is necessary to add to the sawmill investment enough to cover the cost of a planing mill for this purpose, and in computing the cost of lumber an allowance must be made for this planing. In most instances the planing mill is closely connected with the box factory and it is difficult to separate the equipment. For a medium-sized mill a double surfacer and a small band resaw are required. Power is usually furnished by a separate plant from that of the sawmill, though it may be combined with the power plant of the box factory. Planing mills cost from $4,000 to $5,000 for a sawmill of 40,000 feet capacity, from $8,000 to $10,000 for a single-band mill, and $15,000 for a double-band mill. The cost of planing is approximately $1 per 1,000. It is estimated that 30 per cent is the normal proportion of the output that is surfaced in this manner. Upon this basis the prorated cost upon the entire cut would be from 30 to 35 cents per 1,000.

Taking all the above items into consideration, the cost of yard handling at most band mills ranges from $1.65 to $2 per 1,000. A cost of $1.85 per 1,000 may be considered as normal. At smaller mills the yard work involves less detail and costs less.

Most large lumber concerns also operate box and door factories and finishing plants. These are commonly operated in connection with the shipping yards. The principal products are door cuttings, box shooks, moldings, etc., which may be considered as products obtained from the remanufacture of lumber.

TRANSPORTATION TO COMMON CARRIERS.

All sawmills located on common carrier trunk-line railroads load their lumber product for shipment directly into trunk-line cars in the shipping yard. A large proportion of the mills in the sugar and yellow pine region, not so advantageously located, must provide some means of delivering lumber to the trunk-line shipping points.

WAGON HAULS.

The simplest method of transporting lumber is to haul it on wagons with horses. It is the only means at practically all of the small circular mills. At the smallest of these the cut is sold at the mill and each rancher hauls home his purchase. Where the lumber is shipped on the nearest railroad or sold to retail yards in the nearest large town, the sawmill operator maintains a number of teams and wagons for hauling lumber.

The usual lumber outfit consists of a jerk-line team of eight horses hauling two wagons and driven by one teamster. For a 10-mile haul with a moderate amount of adverse grade the average load of lumber is 800 feet per horse. The average load for a team is therefore in the neighborhood of 6,000 feet. Upon an 8 to 10 mile haul such a team makes one round trip daily. Practically all such hauling is done on contract by the owners of the teams and wagons used. The standard contract rate for a haul of 9 or 10 miles with a small amount of adverse grade is $3 per 1,000. The contract rate for a difficult haul of 40 miles in length is $10 per 1,000. The rate for a 40-mile haul all downgrade is about $8 per 1,000. The rate for a haul of 3½ miles is $1.50 per 1,000. These charges are for air-dried lumber.

Loading and unloading is not included in these rates. The sawmill operator consequently maintains a crew in his mill yard to load the wagons, and another crew at the railroad to unload them. Many small concerns load the cars directly from the wagons. Others maintain a small yard alongside the loading spur.

TRACTION HAULS.

Lumber from a few of the larger circular mills is delivered to the railroad by means of traction engines similar to those employed in hauling logs. The trucks are much lighter, however, being merely heavy wagons in some instances. Several trucks are hauled at one time. The direct cost is considerably less than for hauling with horses, but the investment involved is much greater and there is much more risk of delay through breakdowns and inclement weather. On the whole the method serves very well for mills with a moderate output where road conditions are satisfactory. With a large output and consequent heavy traffic it is practically impossible to keep the road in satisfactory condition.

LUMBER RAILROADS.

The most satisfactory method of delivering lumber from the mill to the trunk railroad is by means of a lumber-carrying railroad. All new mills employ this means of transportation wherever the amount of timber is sufficient to justify the investment. Whenever one of the trunk roads can not be induced to build a branch line it is necessary for the lumber operator to construct the road.

Operators prefer to build and operate such lines as private roads in order to avoid certain State regulations as to common carriers. However, in order to secure rights of way it is frequently necessary to make them common carriers. In practically all cases standard gauge is preferred because foreign cars can then be loaded at the mill. In fact, the only circumstance under which a narrow gauge can be considered is when the lumber-drying yard can not be located at the sawmill. Even then the necessity of transferring all supplies and equipment to narrow-gauge cars before delivery at the mill makes the desirability of a narrow gauge doubtful.

The layout and cost of construction of lumber roads are about the same as for logging railroads. Lumber railroads are generally of longer life than logging roads, and the construction can therefore be more permanent. The use of rod engines with heavy trains is usually provided for in laying out the road. In consequence, the maximum grades are 3 or 4 per cent for empty trains and 1 or 2 per cent for loaded trains. Curves are ordinarily not over from 16 to 20 degrees.

The construction materials used are the same as for logging roads, except that the steel is usually 56 or 60 pounds.

The locomotives engaged on lumber hauls vary from 35 to 90 tons in weight. The smaller engines are employed on short, easy hauls. An engine of from 70 to 75 tons in weight is commonly the most satisfactory for the longer lumber hauls. Where the cars are owned by the lumber operator light flat cars are employed. Foreign cars are always used whenever possible.

One 75-ton locomotive and crew will handle the output of a double-band mill for distances up to 30 miles on roads with moderate grades. Two trips are made daily on a 15-mile run and one trip daily on a 30-mile run. A crew consists of a conductor, engineer, fireman, and one or two brakemen. Definite cost figures on the operation of private lumber railroads are not at hand, but it is estimated that dry lumber can be transported for from 50 to 75 cents per 1,000 for hauls of from 10 to 15 miles.

Whenever it is necessary for the railroad to be a common carrier, a separate company owned by the lumber company stockholders is usually formed to operate it. The rates of common carrier railroads are subject to revision and approval by the State Railroad Commission. They are theoretically equal to the proportionate cost of operation plus a reasonable profit on the investment. The local rates upon a number of primarily lumber-carrying railroads follow:

Name of road.	Points.	Mileage.	Rate per 2,000 pounds.
McCloud River Railroad	McCloud to Sisson	17	$2.25
Sugar Pine Railroad	Lyons Dam to Sonora	23	1.35
Boca & Loyalton Railroad	Loyalton to Boca	26	1.50
Sierra Railway	Tuolumne to Oakdale	57	1.60
Butte County Railroad	Sterling City to Barber	30	1.65
San Joaquin & Eastern Railroad	White Pine to El Prado	45	2.25

These local rates are used in combination with trunk-line rates for most California shipments. Points on some of these lines take coast group rates in transcontinental shipments. Air-dried pine lumber has a shipping weight of from 2,500 to 2,700 pounds per 1,000 feet board measure.

LUMBER INCLINES.

Where the sawmill is located within a short distance of a trunk-line railroad but at a considerably higher elevation, an incline is frequently the best and most economical method of delivering the lumber at the loading spur. There are several such inclines in operation, as well as one or two where the lumber is hauled up instead of lowered. An incline located in the central Sierras, and in general typical of them all, is described below.

The upper end of the incline is near the mill and the lower terminus is on a trunk-line railroad. Its length is 4,200 feet and the difference in elevation is 1,500 feet, making an average grade of 38.5 per cent. The maximum grade is 72 per cent on a stretch of 125 feet. The alignment of the track involves three tangents, varying about 5 degrees in direction, joined by two 10-degree curves. The grade at the curves is flattened out to about 10 per cent. The track is narrow gauge with 45-pound rails and 6 by 8 inch by 6 feet redwood ties, dirt ballasted in the usual manner, no other provision being necessary to prevent the track creeping downhill. The initial cost of the construction of the track was between $6,000 and $7,000. The expense of delivering the ties and rail on the ground was very high.

The cars are lowered by a 1-inch cable, supported by 33 ground rollers and three upright rollers. The cable is controlled by a large wooden drum 11 feet in diameter and 14 feet in width, located in a building at the top of the incline. This drum is equipped with a brake wheel 16 feet in diameter and the load is let down by a hand brake. A 14 by 20 inch twin cylinder hoisting engine from 150 to 200 horsepower operates the drum in hauling up the empty car. This equipment has sufficient power to haul up an ordinary sawmill boiler. A 60 inch by 16 foot boiler is required to supply the engine with steam. The cost of the power plant was about $5,000.

The lumber is lowered on 21-foot narrow-gauge flat cars, one car at a trip. The average load per car is about 3,000 feet, and a round trip is made in one-half hour, including switching. The usual average daily output is 40,000 and the normal capacity is 60,000 feet board measure. The crew consists of an engineer, fireman, and brakeman. The cost of operation is calculated at from 35 to 40 cents per 1,000.

LUMBER FLUMES.

Another way of transporting lumber from inaccessible sawmill sites to trunk railroads is by means of flumes. These can be built at a lower cost per mile than railroads and heavier grades may be descended, thus reducing the mileage. The initial cost is at least from 60 to 75 per cent less than for a railroad. Another advantage is that the water used in the flume can in most instances be disposed of for irrigation purposes at the lower end.

The direct cost of fluming lumber is low, but the cost of maintaining the flume is very heavy. The principal disadvantage is that all equipment and supplies used in the logging and sawmill operation must be freighted in with teams for distances of from 40 to 50 miles. The expense of such freighting ranges from $15 to $20 per ton. Other disadvantages are the wear of the lumber in the flume and the difficulty of shipping wide boards. For these and other reasons it is improbable that any more lumber-carrying flumes will be constructed in California, except in instances where a railroad or incline is clearly impracticable.

There are several flumes now in successful operation in California, though the number in use is gradually decreasing. The longest ones are located in the southern Sierras, where longer and more expensive railroads are required to reach merchantable timber than in the northern part of the State. The lengths of the three flumes in the southern Sierras are respectively 42, 56, and 60 miles. On the other hand, one flume located in northern California is only 4½ miles in length.

These flumes consist of a V-shaped box with sides 32 inches wide in the mountains and 48 inches wide where the grade is low and the water sluggish. The angle formed by the sides of the flume is a right angle, and the width across the top is 46 inches where the sides are 32 inches wide. The flume box is supported at distances of either 8 or 16 feet by bents composed of 4 by 6 inch or 6 by 6 inch fir timbers. In the original construction bents were placed at 16-foot intervals, but it has been found advisable to place supports every 8 feet for low trestles. Higher trestles are still constructed with 16-foot bents, but heavier timber and sway and stringer braces are used. Two 4 by 6 inch stringers are supported by the bents. Upon the stringers at intervals of 4 feet are placed the braces which hold the flume box in an upright position.

The cost of constructing flumes varies with the difficulty of preparing the ground for foundations and the average height of the bents; with lumber at $12 per 1,000 it ranges from $20 to $25 per 1,000 board feet, the higher cost being where the average height of the flume is least. The lowest recorded cost is for two flumes in northern California, approximately $4,000 per mile. In the southern Sierras the natural conditions affecting construction are more difficult, and the average cost of construction is about $5,000 per mile. The most expensive flume in that locality is reported to have cost $6,000 per mile. The average amount of material is from 225,000 to 275,000 feet per mile. Farther north the average is not over 175,000 feet.

The maximum grade allowable is about 25 per cent for short pitches. Normally the grade is kept down to between 5 and 10 per cent, with 12 per cent as a maximum. In the San Joaquin Valley the grade is very low. One flume in which the lumber is shipped in bundles has approximately 13 miles on the lower end with a grade of only 0.13 per cent. Another in which the lumber is shipped loose has a similar length of slack water with a grade of 0.26 per cent. The maximum curve used is about 20 degrees. The volume of water required to operate a flume varies from 25 to 35 second-feet.

Lumber is shipped in flumes either loose or in bundles. Shipment in bundles is the most common, and is adapted to flumes having lower grades. The loss of lumber is less than for the other method and fewer herders are required. However, the cost of bundling is considerable and the clamps must be hauled back to the upper end of the flume at a cost of about 1 cent per pound. In either method the lumber is graded and sorted roughly and distributed to the drying piles and shipping skids, which are located along a number of branches feeding into the main flume. In shipping loose in long flumes it is necessary to kiln dry boards from yellow pine and white fir butts and air dry thick or heavy sugar pine boards. This involves a considerable cost for handling in the mill yard and kiln, and loss occurs through stain in air drying. Up to the present the same practice has been customary in fluming in bundles. Recently, however, one company has developed a method of mixing light and heavy lumber in each bundle. All lumber may thus be shipped immediately after sawing, and air and kiln drying at the mill is practically eliminated.

In shipping loose, the lumber is distributed to various shipping skids. The boards are then thrown one at a time into the flume by the shippers.

In bundle shipping the boards are made up in bundles from 10 to 13 inches thick, bound at each end by iron clamps and wooden wedges. The bundles are then thrown into the flume and trains of five or six are fastened together with short rope loops. A crew of 27 men, three men working at each of nine skids, may prepare the bundles for a shipment of about 210,000 feet daily. The remainder of the shipping crew is made up of three men tying the bundles together, one man straightening clamps, one man distributing clamps, one man distributing wedges, and one foreman.

As the bundles pass down the flume they are cared for by herders who prevent jams and watch for flume breaks. On a typical operation the flume is divided into six-mile sections and two herders are assigned to each. With two extra herders on the last half mile the herding crew consists of 20 men and a foreman. At the lower end the bundles are dumped by hand from slack water by a crew of five men. The clamps are then loosened and the boards distributed and handled in the yard in the same manner as if the yard were located at the sawmill.

The cost of flume maintenance is considerable. On the long flumes a repair crew is engaged all winter, and approximately a million feet of lumber is used annually in repairs. The average cost is calculated at 80 cents per 1,000 for two flumes 56 and 60 miles in length and 65 cents per 1,000 for one 42 miles in length. Exclusive of depreciation the average cost of fluming lumber in these long flumes ranges from $1.75 to $1.90 per 1,000. The cost of fluming in short flumes with steep grades all the way is much less. In one such flume 4½ miles in length the lumber is shipped right from the trimmer without drying or sorting. One man is required to ship a daily output of from 60,000 to 70,000 feet. Only two herders are required, but five men are needed at the lower end to take the lumber out of the flume. The direct cost of fluming is thus about 35 cents per 1,000, and the average cost of maintenance is calculated at from 10 to 15 cents per 1,000 on a yearly output of 9,000,000 feet board measure.

PART IV. GENERAL COST FACTORS.

OVERHEAD CHARGES.

Overhead charges include all current expenses which are not directly chargeable to any particular step in the operation; that is, expenses which apply to the entire operation. This is not strictly true of certain items such as taxes and insurance, for the lump sums in which they are paid can be divided into proportionate shares for each part of the operation. Such is not the common procedure, however, and need not be attempted in ordinary calculations of operating cost. Overhead charges are ordinarily computed upon the basis of each 1,000 feet of lumber shipped and may then be applied to each 1,000 feet log scale.

Cruising and layout of logging operations are the first items of overhead cost met with. In private operations cruising is usually done at the time of purchase and may be considered as an additional cost of stumpage. Most of the layout of operations is covered by general superintendence, woods supervision, and engineering.

The cost of protecting the timber from fire is a charge for carrying stumpage rather than for logging. A considerable proportion of the fire fighting done by private operators is, however, for the purpose of protecting chutes, cables, trestles, camps, and the like, and the cost of this part of the fire protection work should be added to the logging cost. National Forest sale contracts require each purchaser to use his employees in fighting fires within a certain defined region. The cost of this work may be properly considered as an extra cost of logging.

TAXES.

Taxes on standing timber are frequently considered by lumbermen as an operating cost; but they are logically a cost of carrying stumpage, and consequently do not enter into the cost of operating. The annual tax rates in the various timber counties vary from $1.64 to $2.60 per $100 of valuation. The average rate is from $1.95 to $2.05. Lumber plants are generally assessed at about 30 or 40 per cent of the value. The lumber on hand in the yard at the time of assessment is valued in about the same way. Assessments are made in April, however, when the lumber stock is generally at its lowest ebb.

INSURANCE.

Lumber operators should carry both fire and liability insurance. Practically all except the small mills carry fire insurance. Most of these carry their own risk because they can not comply with the requirements of fire insurance companies without making an impossible increase in their investment.

Steam sawmills and lumber in yards at steam sawmills may be insured up to about 90 per cent of the actual value. To get a rate for a mill the procedure is to take the standard rate and make certain specified additions to it and deductions from it for designated defects in the plant or for designated protective measures. The standard rate for pine sawmills in California is $3 per $100 of insured value. An addition of $1 is made if box factory, planing mill, or boilers are located in the same or immediately adjacent buildings. On the other hand a deduction of from 50 cents to $1 is made for a good fire-protection system. As a rule the rate for normally well equipped and protected mills with power plant in a detached masonry or corrugated iron building is about $3 per hundred. For small mills in the woods which are safe enough to insure, the rate is about $5 per hundred. For especially well built mills with automatic fire sprinkler systems the rate may be as low as $2 per hundred. These are the rates established by the Board of Fire Underwriters of the Pacific Coast.

The standard rates upon lumber piled in mill yards exposed to no unusual danger are as follows:

Distance from mill.	Rate per hnndred.
250 feet	$2.00
200 feet	2.25
150 feet	2.50
100 feet	3.00
No clear space	3.50

All employees of lumbering companies come under the provisions of the California Workmen's Compensation Act, which provides certain compulsory payments in the case of injury or death of an employee. Operators usually do not wish to assume this risk and prefer to carry liability insurance. This insurance may be placed with any insurance company, provided claims are paid as directed by the State Industrial Accident Commission; or the employer may insure under the State Compensation Insurance Fund. The rates for State and private insurance are the same and are fixed in certain amounts per each $100 paid out in wages. The schedule of rates for State insurance in 1914 was as follows:

Box manufacturers	$2.96
Lath manufacturers	4.81
Lumber yards (commercial)	2.40
Lumber yards (at sawmills)	4.81
Planing and molding mills	3.42
Sawmills	4.81
Logging	4.16
Logging railroads (operation)	11.20
Logging railroads (maintenance and construction)	4.16
Clerical force	.21

The average rate varies in different operations on account of the difference in the number of men employed in the various activities, but for a normal lumbering operation in sugar and yellow pine timber, sawmill included, it is about 4½ per cent of the pay roll. Eliminating labor hired on contract in the lumber yard, the normal wages involved in the production of a thousand feet of lumber amount to about $7. At a rate of 4½ per cent the cost for liability insurance amounts to 32 cents per 1,000. The State Compensation Insurance Fund returned 15 per cent of the premiums to policy holders in 1914.

SELLING.

The cost of selling includes all direct costs of disposing of lumber which have not been deducted from the net price of lumber f. o. b. the mill. The cost of lumber selling agencies and commissions are generally so deducted. However, most large firms have a salesman who travels for the purpose of selling lumber. For the smaller mills this selling may be done by some member of the office force who devotes but part of his time to it. At large double-band mills a sales manager is maintained the year round.

OFFICE AND GENERAL EXPENSES.

Office and general expenses include all clerical help, stationery, upkeep of office buildings, dues, and any other miscellaneous expenditures necessary in the conduct of the business.

SUPERINTENDENCE.

A lumber company with an annual output of, say, 36 million may require a manager and an assistant manager. The manager is usually an official of the company. The combined salaries and expenses are approximately $12,000, but about 20 per cent of this superintendence may be assumed as chargeable to box factories and finishing plants. Thus, in such a case the cost of superintendence is $9,600 per annum, or 27 cents per 1,000 feet. The cost of superintendence is in about the same ratio in the case of smaller operations.

One manager is required for a double-band mill producting about 20 million annually. The manager at a single-band mill operating one shift frequently directly superintends both woods and mill. A proportionate decrease is made in the office force in each instance.

SUMMARY.

To sum up: the cost of selling, general office work, and superintendance at band mill or large circular mill operations is normally from .55 to 70 cents per 1,000, and the total of overhead charges is from $1.25 to $1.40 per 1,000.

At small circular mills, superintendence, office work, and selling are covered by the salary of the operator. Such mills are commonly one-man concerns; and since the owner devotes all his time to the operation he should have a salary as well as a profit on the investment. A mill of 20,000 daily output markets about 3,000,000 feet per annum. At a salary of $1,200 for the operator the cost of superintendence is 40 cents per 1,000.

DEPRECIATION.

All improvements and equipment used in lumbering depreciate in value, and sufficient money must be taken from the business during its course to form a sinking fund to cover this depreciation. The amount of depreciation is measured by the difference between the initial cost and the salvage or residual value at the end of the operation. The common method of figuring depreciation against a body of timber is to determine the total depreciation involved in its exploitation and by prorating this total over the stand to obtain a figure per 1,000 feet. The depreciation per 1,000 may then be applied to the annual cut to determine how large an annual sinking fund is necessary.

Railroads and sawmills which can be used for additional timber have a residual value at the end of the operation much greater than the salvage value. Railroads adapted to a continuous profitable common carrier business may have a residual value practically as large as the initial cost. Improvements and equipment which can not be used any further have only a salvage or wrecking value. Tools, cables, and similar equipment are worn out and must be replaced at frequent intervals, so that they rarely have even a wrecking value. Horse and donkey chutes have no salvage value, except when the material can be utilized as saw logs or made into railroad ties.

The wrecking value of logging railroads which can not be used in place for other purposes is the sale value of the rails for relaying. The rails commonly have a life of from 15 to 20 years; the former where they are lifted and relaid every season, and the latter for more permanent use. Of course, where rails are lifted and relaid often, there is a considerable current loss through breakage and kinking. Geared locomotives, with proper maintenance and repairs, are good for about 20 years service. During that period the boilers must be replaced once. A rod engine should, under similar circumstances, have a slightly longer life, say about 25 years. Cars, either skeleton or flat, have very little salvage value after being used five years. In operations of from 15 to 20 years in length it is generally necessary to figure that the log cars will be renewed at least once.

The sale value of second-hand logging donkeys and similar equipment is very low. In first-class condition they will bring only about 30 per cent of the original factory price, and after five or six years' use donkey engines can no longer be put in first-class condition. The wrecking value is even less. Logging donkeys are ordinarily good for about 9 or 10 years' service. In some instances they may be used as long as 12 years, but if not worn out in 10 years they are at least obsolete in type.

The wrecking value of sawmills is likewise comparatively small. It is confined to the salvage value of the sawmill, planing mill, and dry kiln equipment. The lumber used in the buildings may have a small value in excess of the cost of removing it if the period of use is not too long. Depreciation commonly ranges from $1 to $1.50 per 1,000 feet board measure, depending upon the amount of timber and the extent of the necessary construction.

SUMMARY OF THE COSTS OF TYPICAL OPERATIONS.

A more comprehensive idea of the cost of lumber production may be gained from cost summaries of typical operations of three kinds; namely, a small horse-logging operation, a medium sized circular mill operation, and a large band mill operation. The cost summaries given below are made on the basis of operations of average efficiency, in much the same manner as calculations of operating costs are prepared in appraisals of National Forest stumpage, and are checked by the actual costs of various going lumber companies. The costs of any particular operation may of course differ from these summaries. Costs are in each instance on the basis of lumber shipping tally.

SMALL MILL SUPPLIED BY HORSE LOGGING.

	Per 1,000 feet
Operating costs:	
Logging—	
Felling, limbing and bucking	$0.75
Horse skidding and swamping	1.20
Horse chute hauling	1.40
Chute construction	.50

	Per 1,000 feet.	
Operating costs—Continued.		
Sawmill and yard—		
Sawing	$1.75	
Mill maintenance	.35	
Sorting	.25	
Handling and piling	.60	
Loading	.25	
Transportation—Wagon haul	2.50	
General expense—		
Supervision and office	.70	
Taxes and insurance	.45	
		$10.70
To this should be added an average allowance for depreciation of, say		.80
Total cost		11.50

Mills of this class are usually situated close to the timber and at some distance from either the local market or a common-carrier railroad. In addition, they are often semiportable in character and are moved from time to time in order to be near the timber. Consequently, the logging costs are low, but the cost of lumber transportation is high. In the example above the length of the wagon haul is considered as about 7 miles. No allowance is made for surfacing, as the lumber is usually disposed of rough. Very little expense is necessary for selling because the lumber is generally sold to local users or to some larger producer or box-shook manufacturer.

SINGLE CIRCULAR MILL OPERATION.

	Per 1,000 feet.	
Operating costs:		
Logging—		
Felling, limbing, and bucking	$0.70	
Donkey yarding	1.90	
Loading	.30	
Hauling on trucks	2.20	
Road construction	.20	
Sawmill and yard—		
Sawing	1.70	
Mill maintenance	.35	
Sorting	.25	
Piling and handling	.80	
Surfacing	.30	
Loading	.50	
General expense—		
Superintendence and office (including mill and woods supervision)	.55	
Selling	.20	
Taxes and insurance	.50	
		$10.45
Depreciation—Average		.95
Total cost		11.40

In this example the mill is situated on a common carrier. If it were not, there would be an additional cost for hauling lumber to the railroad. Since the mill is at some distance from the timber, a rather high charge is involved in truck hauling with horses or a traction engine. In an operation of this type more care and work in the yard is necessary than in smaller operations. A planer is usually operated in connection with the mill and a portion of the cut surfaced before sale. Loading on cars is a more expensive operation than loading on wagons for hauling.

LARGE BAND MILL OPERATION.

	Per 1,000 feet.	
Operating costs:		
Logging—		
Felling	$0.22	
Bucking	.08	
Limbing	.35	
Yarding labor, etc	1.58	
Yarding maintenance	.22	
Cables	.20	
Loading	.25	
Railroad operation	.50	
Railroad maintenance	.75	
Unloading	.03	
Railroad construction	.80	
Woods supervision	.22	
		$5.20
Sawmill—		
Pond	.07	
Sawing	1.15	
Sawmill supplies	.18	
Sawmill maintenance	.32	
Sawmill supervision	.05	
Sorting	.25	
		2.02
Sawmill yard—		
Distributing	.25	
Piling	.40	
Surfacing	.35	
Kilning	.30	
Loading	.50	
Supervision and upkeep	.15	
		1.95
General expense (overhead)—		
Taxes and fire insurance	.40	
Liability insurance	.35	
Selling	.25	
Superintendence and office	.40	
		1.40
Depreciation—Average		1.10
Total cost		11.67

The above list of costs does not take into account any finishing or remanufacture of lumber other than surfacing for shipment. By taking greater care of its lumber and paying more attention to selling, a large mill generally sells its product more advantageously than a small one. Since the costs at large mills vary considerably throughout the California pine region, those given above may be considered as somewhat ideal for a mill located on a common carrier and with a logging road of moderate length. Inspection of operating-cost records shows that, exclusive of profit, interest, and stumpage, the bulk of the lumber produced at large mills in this region is placed on cars at common-carrier railroad points, rough or surfaced for shipping, at from $11.50 to $12.50 per 1,000 feet. Mills with flumes or branch-line lumber roads, severe logging conditions, or inefficient plants may have to pay more.

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BULLETIN No. 441

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WM. A. TAYLOR, Chief

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THE ACTION OF MANGANESE UNDER ACID AND NEUTRAL SOIL CONDITIONS.

By J. J. Skinner and F. R. Reid, *Biochemists, Office of Soil-Fertility Investigations.*

CONTENTS.

	Page.
Introduction	1
Effect of manganese on Arlington soil under acid conditions	2
Oxidative power of plats with and without manganese under acid conditions	5
Effect of manganese on Arlington soil under neutral conditions	6
Oxidative power of plats with and without manganese under neutral conditions	9
Summary	11

INTRODUCTION.

Investigations of the action of manganese on plants and soils have been conducted by the Office of Soil-Fertility Investigations both in the laboratory and in the field for several years.

Manganese is universally found in soils and plants. Robinson,[1] who examined 26 American soils, found the content of manganese (MnO) to be from 0.01 to 0.51 per cent, the average being 0.071 per cent, and Kelley [2] found in Hawaiian soils amounts varying from less than 0.1 to 9.74 per cent Mn_3O_4.

A number of investigators have studied the effect of manganese on plants in both water and soil cultures, and from the evidence at hand it seems that in most cases manganese in small amounts exercises a stimulating action on growth. A general review of the literature on the subject has been given in former papers of members of

[1] Sullivan, M. X., and Robinson, W. O. Manganese as a fertilizer. U. S. Dept. Agr., Bur. Soils Circ. 75, 3 p. 1913.

[2] Kelley, W. P. The influence of manganese on the growth of pineapples. Hawaii Agr. Exp. Sta. Press Bul. 23, 11 p., n. d.

——— Manganese in some of its relations to the growth of pineapples. *In* Jour. Indus. and Engin Chem., v. 1, no. 8, p. 533-538. 1909.

NOTE.—The results given in this bulletin throw further light on the effect of this catalytic fertilizer under various soil conditions. That its effect is dependent on the reaction of the soil is demonstrated. The bulletin is of interest to scientific investigators, to manufacturers of catalytic fertilizers, and to those growers whose technical training induces them to experiment with new substances to increase or control crop production.

the staff of the Office of Soil-Fertility Investigations and others,[1] so its repetition here is not deemed necessary.

Working with soil extracts [2] from poor, unproductive soils, manganese salts were found to increase the oxidizing power of the plant roots grown therein and increased the growth of the plants. With extracts from good, fertile soils the oxidative power of the plants was increased, but it was not attended by an increase in growth. This was attributed to excessive oxidation in the soil solution. The plant tips and leaves themselves showed indications of this excessive oxidation. Similar results were obtained with soil in pots. The poor, unproductive soils were improved by manganese, while good soils were not further benefited. The best results were secured with small amounts varying from 5 to 50 parts per million of the element manganese.

Schreiner and Sullivan [1] have further pointed out that the oxidative power of the soil is dependent in part on the nature of the organic matter. Thus, when salts of manganese, iron, calcium, etc., were added to soil of slight oxidative power, oxidation was but slightly increased until certain kinds of organic matter, such as citric, malic, tartaric, and glycolic acids or their salts, were added, when marked improvement in oxidation took place.

EFFECT OF MANGANESE ON ARLINGTON SOIL UNDER ACID CONDITIONS.

Field tests with manganese sulphate were inaugurated on the experiment farm of the Department of Agriculture at Arlington, Va., in 1907. The results secured from 1907 to 1912 have already been published.[2] The experiment has been continued with some modification, and the additional data throw considerable light on the action of manganese in soils of this character. The soil in which these experiments were made is a silty clay loam, low in organic matter. The physical condition of the soil is rather poor, and great care had to be practiced in cultivation to keep it in a good physical condition. The ground is level and has surface drainage, and the soil throughout these manganese plats and their controls is uniform, so the results obtained should not be considered as unduly influenced by irregularities due to nonuniformity of the soil in different plats. The soil is of an acid nature.

The ground on which these experiments were made consists of two parallel strips of land, each 1 rod wide and separated by a 3-foot path. Each strip is divided into seven plats of 1 square rod, with

[1] Schreiner, Oswald, and Sullivan, M. X. Studies in soil oxidation. U. S. Dept. Agr., Bur. Soils Bul. 73, 57 p. 1910.

Kelley, W. P. The function and distribution of manganese in plants and soils. Hawaii Agr. Exp. Sta. Bul. 26, 56 p. 1912.

[2] Skinner, J. J., Sullivan, M. X., et al. The action of manganese in soils. U. S. Dept. Agr. Bul. 42, 32 p. 1914.

paths $2\frac{1}{2}$ feet wide separating the plats. One strip, or a series of seven plats, was treated with manganese sulphate; the other strip of seven plats was not treated and served as a control, or check. Seven crops, rye, wheat, timothy, clover, corn, cowpeas, and potatoes, were grown on both the treated and untreated plats, which lie side by side in the two strips. The crops on the plats were not rotated, but each crop grew year after year on the same plat. The manganese sulphate was applied annually, before the crops were planted, at the rate of 50 pounds per acre. The corn, cowpeas, and potatoes were planted in the spring of each year and harvested in the fall, and the wheat and rye were planted in the fall and harvested the next July. The timothy and clover plats were planted in 1907, and the ground was again plowed and reseeded in 1909.

The results for the six years from 1907 to 1912, inclusive, are given briefly in Table I and will permit a short discussion here, the reader being referred to the earlier publications previously mentioned for the results in detail. The yields are calculated to pounds and bushels per acre and are so given in the table. The wheat and rye were not thrashed, the yield being given in weight of straw plus grain. The timothy and the clover were a failure on this soil; these plats produced practically no yield and no results were obtained.

TABLE I.—*Effect of manganese sulphate on the yields per acre of wheat, rye, cowpeas, corn, and potatoes on an acid soil treated for six successive years (1907 to 1912, inclusive).*

Year.	Wheat.			Rye.			Cowpeas.		
	Untreated.	Treated with manganese sulphate.	Increase or decrease of manganese plat.	Untreated.	Treated with manganese sulphate.	Increase or decrease of manganese plat.	Untreated.	Treated with manganese sulphate.	Increase or decrease of manganese plat.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1907							8,320	6,720	−1,600
1908	4,960	4,320	− 640	5,280	4,160	−1,120	8,800	6,560	−2,240
1909	4,160	3,680	− 480	4,160	4,640	+ 480	5,920	4,480	−1,440
1910	4,000	3,520	− 480	1,920	1,600	− 320	4,320	3,360	− 960
1911	4,000	3,360	− 640	3,680	4,000	+ 320	6,720	5,600	−1,120
1912	3,840	2,400	−1,440	2,240	2,720	+ 480	3,360	3,520	− 160

Year.	Corn.						Potatoes.		
	Untreated.		Treated with manganese sulphate.		Increase or decrease of manganese plat.		Untreated.	Treated with manganese sulphate.	Increase or decrease of manganese plat.
	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.			
	Pounds.	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1907	9,120	60	10,400	40	+1,280	−20	221	152	−69
1908	4,160	71	3,360	51	− 800	−20	120	80	−40
1909	4,320	20	3,040	17	−1,280	− 3	181	221	+40
1910	6,240	40	4,320	23	−1,920	−17	147	96	−51
1911	4,800	40	4,000	20	− 800	−20	243	152	−91
1912	5,440	46	2,720	9	−2,720	−37	85	61	−24

Table I shows that wheat was reduced in yield each year by the manganese, the decrease varying from 480 to 1,440 pounds per acre. With rye, the yield was increased in 1909, 1911, and 1912, and was decreased in 1908 and 1910. With corn, there was a decrease each year except 1907, when the yield of stover was larger. The growth of cowpeas was also decreased, this decrease varying from 160 pounds per acre in 1912 to 2,240 pounds in 1908. Potatoes were likewise affected, there being a smaller yield in the manganese plat each year except in 1909, when there was an increase over the check plat of 40 bushels per acre.

Acidity tests of the various plats were made in 1912. The results of these determinations show that the manganese tests were made under acid conditions.

The lime-requirement determinations were made by means of the Veitch method.[1] Table II shows the amount of lime required according to this method for each plat to produce a neutral condition in the soil. The soil in each plat required approximately a ton of lime per acre. Where wheat was grown, the manganese and the untreated plats had the same lime requirement. Where rye, corn, and cowpeas were grown, the manganese plats had a higher lime requirement than the untreated plats. With rye, the manganese plat required 2,492 pounds and the untreated plat 2,136 pounds of lime per acre. With corn, the manganese plat required 2,492 pounds and the untreated plat 1,780 pounds per acre. With cowpeas, the manganese plat required 2,492 pounds and the untreated plat 2,136 pounds per acre. Where potatoes were grown, the untreated plat had a greater lime requirement than the manganese plat, the manganese plat requiring 2,451 pounds of lime per acre and the untreated plat 2,743 pounds.

TABLE II.—*Lime ($CaCO_3$) requirement per acre of the various plats, to a depth of 6 inches.*

Plats.	Wheat.	Rye.	Corn.	Cowpeas.	Potatoes.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Treated with manganese	1,780	2,492	2,492	2,492	2,451
Untreated	1,780	2,136	1,780	2,136	2,743

[1] Veitch, F. P. The estimation of soil acidity and the lime requirements of soils. *In* Jour. Amer. Chem. Soc., v. 24, no. 11, p. 1120–1128. 1902.

——— Comparison of methods for the estimation of soil acidity. *In* Jour. Amer. Chem. Soc., v. 26, no. 6, p. 637–662. 1904.

OXIDATIVE POWER OF PLATS WITH AND WITHOUT MANGANESE UNDER ACID CONDITIONS.

Bertrand[1] showed that manganese played an essential part in the oxidation by the so-called oxidizing enzym laccase. Further, since manganese increased the oxidizing power of a number of soils tested by the Office of Soil-Fertility Investigations and it has been found that a number of soils of strong oxidizing power contain considerable manganese, some of which was in the highly oxidizing form of MnO_2, it became of interest to determine whether the manganese had any accelerating effect on the oxidation in the soil of the field plats planted with wheat, rye, corn, cowpeas, and potatoes.

In 1912 composite samples from five borings to the depth of 6 inches were taken of the manganese plats and check plats (1) early in April, (2) late in May, and (3) in August. The oxidation readings were made on the air-dried samples within two weeks after collection.

When 10 or 20 grams of soil are shaken two or three times with 50 to 70 c. c. of a 0.125 per cent water solution of aloin, the aloin solution is changed in a few minutes from a bright yellow to a cherry red. After the soil has stood for about an hour and has settled, the somewhat turbid solution is decanted and centrifuged, the supernatant liquid drawn off, and the depth of color of the different solutions compared by means of a Schreiner colorimeter, either with each other or with colored glass of a shade of red matching the oxidized solutions. In the present experiment the oxidation reading was made against a glass standard which matched in tint the red color produced in the aloin solution by the sample of wheat soil collected in the spring. Ten grams of soil were employed for each test. The relative oxidation in the manganese plats and the check plats is given in Table III.

TABLE III.—*Relative oxidation in plats treated with manganese sulphate and in the corresponding check plats growing the same crops (wheat soil in April being taken as 100).*

Crop.	April.		June.		August.	
	Untreated plats.	Plats treated with manganese.	Untreated plats.	Plats treated with manganese.	Untreated plats.	Plats treated with manganese.
Wheat	100	95	110	130	55	64
Rye	131	105	131	105	78	60
Corn	110	100	130	131	87	75
Cowpeas	66	64	105	110	53	53
Potatoes	87	60	91	78	53	55

[1] Bertrand, Gabriel. Sur les rapports qui existent entre la constitution chimiques des composés organiques et leur oxydabilité sous l'influence de la laccase. *In* Compt. Rend. Acad. Sci. [Paris], t. 122, no. 20, p. 1132-1134. 1896.

—— Sur l'intervention du manganèse dans les oxydations provoquées par la laccase. *In* Compt. Rend. Acad. Sci. [Paris], t. 124, no. 19, p. 1032-1035. 1897.

With the exception of the wheat plat, where there is shown a slight increase as an average of the three determinations, the addition of manganese sulphate has not increased the oxidative power of the soil, and in a number of instances it has lessened oxidation. The soil in general has a tendency to be acid in character and at best has not a strong oxidizing power. If the first determination, made in April, is considered (that is, the oxidative power of the plats at a time when there is little or no growth) the oxidation in the manganese plat is less in every instance than that of the check plat. This period is the best one for testing the oxidation effect of manganese unmodified by plant growth. The lessened oxidation produced by manganese sulphate is in harmony with the lessened yields on the same plats under treatment with manganese. In 1912, for instance, the year in which the oxidation was tested, the yield, as previously shown, of wheat, corn, and potatoes was less on the manganese plat than on the untreated plat, while rye only showed a slight increase and the yield of cowpeas was practically the same.

In the second determination, made in June, the oxidative power of the manganese plat is on the average more like that of the check plat.

In the third determination, made in August, shortly after the wheat and rye had been taken off, the manganese plat was on the average again less than the check plat.

As previously pointed out, the manganese plats, with the exception of the potato and the wheat plats, showed a higher lime requirement than the check plats. Under acid conditions the formation of organic compounds capable of acting as oxygen carriers or as activators of inorganic oxidizing compounds, such as manganese salts, is much lessened or entirely inhibited. This is also indicated from the results with the acid soil under investigation, for the addition of manganese did not increase the oxidizing power of the soil nor, indeed, of plants growing therein. This oxidizing power of the plants was tested in the case of wheat. By carefully removing the soil from the young wheat plants growing on the plats, the oxidizing power of the intact roots when placed in an aloin solution was found to be no greater in the case of the plants from the manganese plat than from the check plat. The relative oxidation was 97 and 100, respectively.

EFFECT OF MANGANESE ON ARLINGTON SOIL UNDER NEUTRAL CONDITIONS.

As the manganese had no beneficial effect on the soil under acid conditions, the experiment was continued and the soil neutralized as nearly as possible by applying lime from year to year. Three years' results have now been secured. Each year before planting, the lime requirement of the plats was determined by the Veitch method and an excess of lime added to both the check and manganese plats. The experiment was conducted as in previous years. Manganese sulphate was applied each year in amounts of 50 pounds per acre and the same crops were grown on the same plats as before except on the clover plats, which were planted in string beans. The timothy plats were again plowed and reseeded.

In September, 1912, the plats were limed, using 500 pounds per acre $CaCO_3$ in excess of the amounts required by the soil as determined by the Veitch method, given in Table II. The manganese sulphate was applied to the wheat, rye, and timothy plats on September 15, and the plats and their checks were seeded. The corn, cowpea, bean, and potato plats received their applications in the spring of 1913, shortly before seeding time.

The results for 1913 are given in Table IV.

TABLE IV.—*Effect of manganese sulphate on the yields of wheat, rye, timothy, beans, corn, cowpeas, and potatoes in 1913.*

Area and treatment.	Wheat.	Rye.	Timothy.	Beans.		Corn.			Cowpeas.	Potatoes.	
				Pods.	Vines.	Stover.	Ears.				
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*	*Bush.*
Per square rod:											
Untreated	13	15	36	15	18	24	13	......	32	24	......
Treated with $MnSO_4$	11	14	38	17	18	21	11	......	29	21	......
Per acre (calculated):											
Untreated	2,080	2,400	5,760	2,400	2,800	3,840	......	30	5,120	......	64
Treated with $MnSO_4$	1,760	2,240	6,080	2,720	2,800	3,360	......	25	4,640	......	56

The results show that the manganese sulphate has again depressed the yield, but only slightly as compared with previous years. The only cases where the manganese plats produced larger yields were with timothy and beans, but the differences are very small.

The soil was again examined for acidity early in August and the wheat, rye, corn, cowpea, and potato plats were again found to be acid; the timothy and string-bean plats, however, were neutral. This was true of both the check plat and the manganese-treated plat. The lime requirement of the different plats, expressed in pounds of $CaCO_3$ per acre, is given in Table V.

TABLE V.—*Lime ($CaCO_3$) requirement per acre of the different plats to a depth of 6 inches.*

Plats.	Wheat.	Rye.	Timothy.	Beans.	Corn.	Cowpeas.	Potatoes.
	Pounds.	*Pounds.*			*Pounds.*	*Pounds.*	*Pounds.*
Untreated	1,400	1,000	Neutral.	Neutral.	1,200	900	1,200
Treated with $MnSO_4$	1,200	1,200	...do....	...do....	700	900	900

The amounts of lime added in the fall of 1912 were not sufficient to keep this soil neutral during the next growing season except in the two cases mentioned, and it is noted that these are the two plats on which the manganese produced the increase over its check.

For the 1914 crops, lime ($CaCO_3$) was added to all the plats at the rate of 2,000 pounds per acre, except the timothy and bean plats, which received an application of 500 pounds per acre. To the timothy plats lime was added on the surface to the sod; on the other plats the lime was applied to the surface and well harrowed, so as to thoroughly mix the lime with the soil to a considerable depth. The reaction of the soil was tested four weeks after the lime was applied and periodically during the growing season. The soil in all the plats showed no acidity during the entire season.

The manganese sulphate was applied and the crops were grown in 1914 as before. The yields for the year are given in Table VI.

TABLE VI.—*Effect of manganese sulphate on the yields of wheat, rye, timothy, beans, corn, cowpeas, and potatoes in 1914.*

Area and treatment.	Wheat.	Rye.	Timothy.	Beans.		Corn.			Cowpeas.	Potatoes.	
				Pods.	Vines.	Stover.	Ears.				
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*	*Bush.*
Per square rod:											
Untreated	23	37	38	17	20	28	14	......	23	23	......
Treated with $MnSO_4$	28	57	43	20	24	31	16	......	27	21	......
Per acre (calculated):											
Untreated	3,680	5,920	6,080	2,720	3,200	4,480	......	32	3,680	......	61
Treated with $MnSO_4$	4,480	9,120	6,880	3,200	3,840	4,960	......	36	4,320	......	56

Table VI shows that the manganese-treated plat with each crop except potatoes produced a larger yield than its check. The largest increase was with the rye crop. The grain was thrashed in this case, the check plat yielding 4 pounds of grain and the manganese plat 7½ pounds. The straw was increased 3,200 pounds per acre. The rye growing on the check and manganese plats is shown in figures 1 and 2 and the harvested straw and grain in figure 3. In the case of the other crops wheat was increased 800 pounds, timothy 800 pounds, bean vines 640 pounds, bean pods 480 pounds, corn stover 480 pounds, corn grain 4 bushels, and cowpea hay 640 pounds per acre. With potatoes, there was no increase; in fact, a decrease of 5 bushels per acre is shown.

For the 1915 crop all the plats were again limed at the rate of 2,000 pounds per acre, the lime being applied in the fall of 1914. The manganese was applied as usual. Acidity tests of the soil were made periodically, and again the soil was found not to become acid during the growing season of 1915. The yields for 1915 are given in Table VII.

TABLE VII.—*Effect of manganese sulphate on the yields of wheat, rye, timothy, beans, corn, cowpeas, and potatoes in 1915.*

Area and treatment.	Wheat.	Rye.	Timothy.	Beans.		Corn.			Cowpeas.	Potatoes.	
				Pods.	Vines.	Stover.	Ears.				
Per square rod:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*	*Bush.*
Untreated	11	18	41	25	31	48	30	......	31	19	......
Treated with $MnSO_4$	14	26	45	27	34	54	33	......	40	19	......
Per acre (calculated):											
Untreated	1,760	2,880	6,560	4,000	4,960	7,680	......	68	4,960	......	40
Treated with $MnSO_4$	2,240	4,160	7,200	4,320	5,440	8,640	......	75	6,400	......	40

The effect of manganese on all the crops in 1915 was somewhat similar to its effect in 1914. Considerable increases were produced

FIG. 1.—Rye on an untreated plat.

with each crop except potatoes. In this case the yield was the same in the check plat and manganese plat. Again the largest increase was secured with rye.

OXIDATIVE POWER OF PLATS WITH AND WITHOUT MANGANESE UNDER NEUTRAL CONDITIONS.

In July, 1915, samples of soil were taken from each plat, as previously described for the work done in 1912, in order to determine the oxidizing power. The relative oxidation in the check plats and manganese plats is given in Table VIII. The check plat in each case is taken as 100 and compared with the manganese plat growing the same crop.

TABLE VIII.—*Relative oxidation in plats treated with manganese sulphate and in the corresponding check plats growing the same crops.*

Plats.	Wheat.	Rye.	Timothy.	Beans.	Corn.	Cowpeas.	Potatoes.
Untreated	100	100	100	100	100	100	100
Treated with manganese	283	132	75	109	76	107	105

With the exception of the timothy and corn plats, the addition of manganese sulphate has increased the oxidizing power of the soil. In general, however, this increased oxidation agrees with the increased yields in the limed soil. This is in contrast to the action of manganese in this soil while under acid conditions, which caused less oxidation in the soil and a decreased growth. Under acid conditions the

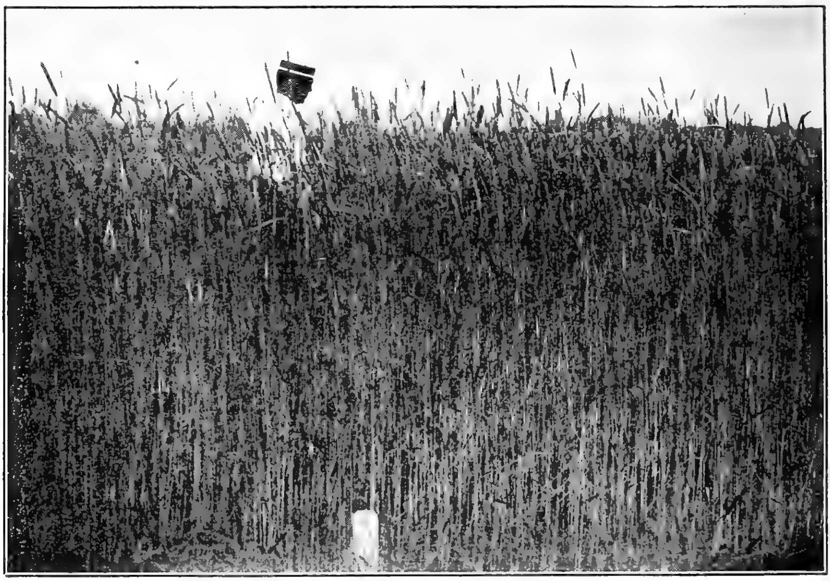

FIG. 2.—Rye on a plat treated with manganese.

effect of oxidizing compounds, such as manganese salts, is much lessened or entirely inhibited, while under neutral or slightly alkaline conditions this oxidizing power is stimulated. The soil under study is of an acid character, naturally poor in its oxidizing power, and is physically bad. Methods of cultivation which loosen and aerate the soil and chemicals which increase its oxidizing power should increase its crop-producing power. With the acid soil, where manganese gave decreased yields, conditions were such that stimulating action on plants and microorganisms of the soil did not come into play; or, possibly on account of the acidity of the soil, the effect of the manganese led to a stimulation of other biological processes, acting on the organic soil constituents in such a manner as to produce changes injurious to the growing crops.

The stimulation of the oxidative processes by manganese was favorable in the soil kept under neutral or alkaline conditions by applying lime year by year, and these oxidative processes acting in turn on the organic or inorganic constituents of the soil produced changes beneficial to the growing crops.

SUMMARY.

In a 6-years' field test of manganese sulphate used at the rate of 50 pounds per acre on an acid silty clay loam, its effect each year

FIG. 3.—Effect of manganese on rye. Straw and grain from check plat, on the left; from plat treated with manganese, on the right.

was not beneficial to the crops grown—wheat, rye, corn, cowpeas, and potatoes. The soil in the various plats required from 1,780 to about 2,750 pounds of $CaCO_3$ to neutralize the first 6 inches. The soil is of an acid character, is low in organic matter, rather bad physically, and naturally has a poor oxidizing power. The oxidative processes in the soil were lessened by manganese in most of the plats under the acid condition.

The action of manganese was studied on the same plats, kept neutralized with lime for the three succeeding years following the experiment with the soil in an acid condition.

The productivity of the soil was increased by manganese under this neutral or slightly alkaline condition. With wheat, rye, timothy, beans, corn, and cowpeas the yields were increased, while with potatoes the yield was practically the same in the treated and the check plats.

The oxidative power of the neutralized soil was also increased by manganese, which is in accord with the results of former investigations, which have shown that the oxidation by manganese salts is greater under slightly alkaline conditions.

The action of manganese in decreasing the oxidation in the soil while acid is in harmony with the decreased yield, and its action in increasing the oxidation of the neutralized soil is in harmony with the increased yield. The action of manganese in the acid soil was probably to stimulate the life processes in the soil, acting on the organic matter in such a way as to produce changes which resulted in a lessened crop-producing power, while its action in the neutralized soil was such as to stimulate oxidation and other biological processes, acting on the organic soil constituents and producing changes favorable to the growing plants.

These results on the behavior of manganese as a so-called catalytic fertilizer when acting under acid or neutral soil conditions show that no profitable return is to be expected in soils of a persistent acid tendency until such soils are limed.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 442

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER January 25, 1917

POSSIBILITY OF THE COMMERCIAL PRODUCTION OF LEMON-GRASS OIL IN THE UNITED STATES.

By S. C. Hood,

Scientific Assistant, Drug-Plant and Poisonous-Plant Investigations.

CONTENTS.

	Page.
Introduction	1
Soil and climatic requirements of lemon grass	2
Propagation	3
Fertilizers and cultivation	3
Harvesting	4
Distillation	6
Varieties	7
Factors affecting the yield of lemon-grass oil.	8
Factors affecting the citral content of lemon-grass oil	9
Solubility of lemon-grass oil in alcohol	10
Commercial possibilities	11

INTRODUCTION.

Lemon-grass oil is the volatile oil distilled from the plant known botanically as *Cymbopogon citratus* DC. and commonly called lemon grass (fig. 1). It is lemon yellow to brownish in color, with a strong odor resembling that of the lemon verbena, and for many years has occupied a prominent place in the perfume industry. The value of this oil depends almost entirely upon its content of citral, which is used in the manufacture of ionone, or artificial violet. Considerable use is also found for the oil in the soap industry.

The principal regions where lemon-grass oil is produced are the Travancore Province and Madras Presidency of India and the island of Ceylon. Small quantities are regularly produced in other parts of the East Indies, and from time to time in many other parts of the world.

Exact figures are not available regarding the consumption of lemon-grass oil in the United States, but estimates place it at about 100,000 pounds annually.

For the past eight years the Bureau of Plant Industry has been conducting experiments in the growing of lemon grass in central

Florida, and during the course of the experiments field tests have been made with 13 varieties secured from eight different parts of the world.

SOIL AND CLIMATIC REQUIREMENTS OF LEMON GRASS.

The best results with lemon grass have been obtained on well-drained sandy loam (fig. 2), but this plant also does well on light sand, such as the high pine lands of the Florida peninsula. Newly cleared sandy pine land without the previous application of lime has

FIG. 1.—Two plants of lemon grass four months after planting.

also given good results. Soil which is poorly drained or underlain by hardpan within 3 feet of the surface should not be planted to lemon grass. Field tests have not been made on heavy clay lands, but the successful cultivation of the crop on that type of soil is regarded as doubtful.

The climatic requirements of lemon grass are subtropical. A winter temperature of 28° F. has killed the plants to the ground, while 24° has killed the roots. However, the crop may be planted with safety where the temperature does not fall below 25° F., and under certain conditions even a slightly lower temperature may not cause serious damage.

PROPAGATION.

Lemon grass does not produce seed in this country, although occasionally an abortive flower spike may be found on old, neglected plants. Propagation, therefore, is effected by division of the clumps. From each clump 25 to 50 divisions may be separated easily by tearing them off from the base of the mature plant. This should be accomplished by a sidewise pull, so that a few root fibers will be retained on each division. In case the old plants are to remain in their places the required number of divisions can be secured by pulling them off

FIG. 2.—Lemon grass 3½ feet high six months after planting on sandy pine land.

from the outer edge of the old clump. With a little practice these may be removed without loss of root fibers.

Before planting, the tops of the divisions should be cut back to about 3 inches (fig. 3). The plants should be set in the early spring in rows 3 feet apart and about 18 inches apart in the row. This work should be done just after a rain or at a time when the soil is sufficiently moist not to require artificial watering.

FERTILIZERS AND CULTIVATION.

The results obtained from experimental fertilizer plats seem to indicate that on the sandy Florida soils rather more potash is required by lemon grass than by most grasses. Analysis shows a considerable variation in the percentage of nitrogen, phosphoric acid, and potash present in the plants of the different varieties tested. The results secured with one variety, which may be taken as a type, show that 5 tons of lemon grass contain 20.32 pounds of nitrogen, 33.20 pounds of potash, and 18.75 pounds of phosphoric acid. In the fertilizer tests a better growth was secured when the potash was applied in the form of the sulphate, and the results were more satisfactory when part of the nitrogen was applied in organic form. In the tests which have been made a fertilizer having 4 per cent nitrogen, 5 per cent potash, and 8 per cent phosphoric acid, applied at the rate of 600 pounds to the acre, has given the best results with the least cost. On soils of higher fertility a smaller quantity could be used. Although the use of larger quantities of fertilizers will give a heavier growth, it

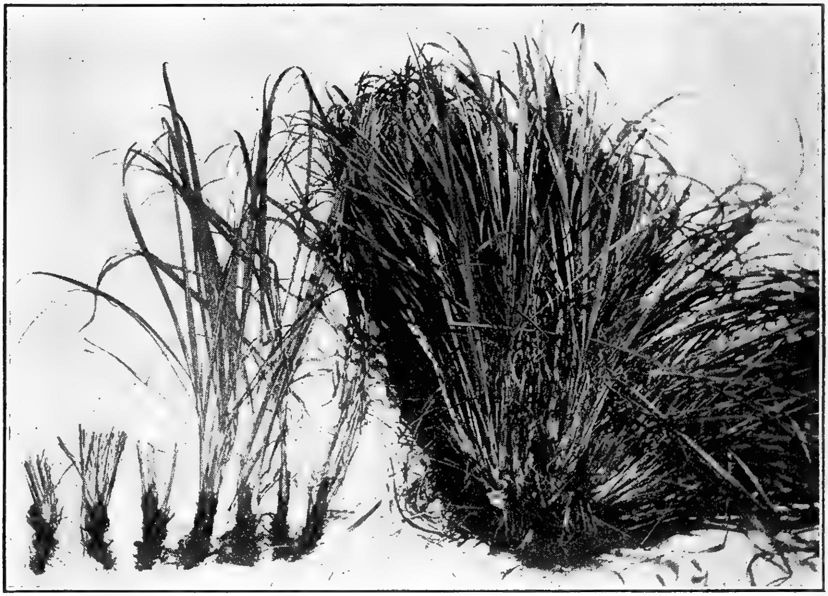

FIG. 3.—A mature clump of lemon grass, with divisions taken from it and trimmed for planting.

is by no means certain that the additional cost will be met by the increase in the crop.

As soon as the plants have become well established in the field the fertilizer should be given as a side application and well worked in at the first cultivation. Cultivation should be frequent throughout the spring, to conserve the soil moisture, and throughout the summer all weeds should be kept down, as a few ill-smelling weeds in the crop at harvest time will greatly injure the odor of the oil. After the first year, only slight cultivation is needed, since after it is well established lemon grass tends to retard weed growth.

HARVESTING.

The first cutting should be made four or five months after planting, at which time the plants should be from $2\frac{1}{2}$ to 3 feet high and the bunches from 8 to 10 inches in diameter. Although the plants will continue to grow throughout the summer, it has been found that after a certain size has been reached the increase in weight is less rapid; hence, it is more profitable to harvest the crop at the time stated and allow a new growth to develop. In the early fall of the first year a second cutting can be secured. After the first year the growth in the spring is more rapid and three harvests a year can be obtained. Harvesting can be accomplished by the use of a mowing machine so adjusted as to cut the plants about 8 inches above the ground. The cut material can be raked up with a horserake run crosswise of the rows.

In order to determine the proper stage and height at which the plants should be cut to produce the best yield and quality of oil, a number of tests were made, covering several years. In 1908 the plants were cut when they were 2 feet high. They were then tied in bundles, the bundles cut into three 8-inch lengths, and each portion distilled separately. The yield of oil obtained from each portion, together with the citral content of the oils, is shown in Table I.

TABLE I.—*Yield and citral content of lemon-grass oils distilled from plants 2 feet high.*

Portion of plant distilled.	Yield of oil.	Citral content of the oil.[1]
	Per cent.	*Per cent.*
Upper third	0.46	70
Middle third	.24	78
Lowest third	.10	82

[1] The citral content throughout all the experiments was determined by the sodium-sulphite method.

From these results, which are borne out by additional data obtained in succeeding years, the conclusion is evident that close cutting will not be profitable, because of the low oil content in the lower portion of the plant.

For the purpose of determining whether the hauling cost could be reduced by drying the plants before taking them to the still, the following test was made: A quantity of fresh plants was collected, well mixed, and divided into three portions. The first portion was distilled green, the second portion was exposed to the sun for several hours until the blades were nearly dry, and the third portion was dried in a loft for several hours at 110° F. The two dried portions were then distilled separately and the yield of oil calculated on the original green weight of the material. The results secured, together with the citral content of the oils, are given in Table II.

These results show that there was considerable loss of oil by drying the plants. In the case of the sun-dried plants the loss on a 4-ton crop would be 1.8 pounds of oil, or, at the prices prevailing for 1915, a loss of $3.84, which would more than pay for the extra hauling charge. Drying the plants seems to have no effect on the citral content of the oil, but on storing it was found that the solubility of the oil in alcohol diminished more rapidly in the oils from the dried material.

TABLE II.—*Yield and citral content of lemon-grass oils distilled from green and from dried plants.*

Condition of material.	Weight of material (green).	Weight of material (dried).	Yield of oil (based on green weight of material).	Citral content of the oil.
	Pounds.	*Pounds.*	*Per cent.*	*Per cent.*
Fresh	78.1		0.37	78
Sun dried	93.1	58.3	.31	78
Artificially dried	100.3	62.7	.32	79

DISTILLATION.

The apparatus required for the distillation of lemon-grass oil does not differ from that in general use for the distillation of other volatile oils. Before distilling the plants it has been found advisable to run them through a fodder cutter, in order to permit closer packing in the retort. From the data at hand it is estimated that if the plants are cut into 2-inch lengths a retort will hold 100 pounds of material for every 6 cubic feet of space, but if the plants are put in whole the quantity which the retort can hold will be somewhat less. The closer packing, however, in no way facilitates distillation.

In a retort having a capacity of 30 cubic feet a charge of 3,000 pounds can be distilled in 2 to 2½ hours by the steam which may be readily generated in a small farm boiler, and by the use of a larger volume of steam the time can be much reduced.

In this connection it is interesting to note that distillation under 20 pounds pressure in the retort increased the yield of oil, but gave an oil of very dark color and with lower citral content.

After the oil has been distilled it should be freed from water so far as possible in a separatory funnel, then dried by shaking with anhydrous calcium chlorid, and filtered. It should be stored in well-filled air-tight containers in as cold a place as possible until ready to be shipped to market. The shipping can be done in new and clean tin cans without injury to the product.

In order to determine whether any appreciable quantity of oil would be lost by discarding the distilled water coming over with the oil, a series of tests was made in 1915. The water from a number of charges of several pounds each was retained and each lot separately redistilled. In the apparatus used in the experiments about 1 gallon of water was secured for each 22 pounds of herb in the charge. The average of the results secured by the redistillation of this water showed that 1.2 gram of oil was dissolved in each gallon of water, a quantity too small to make its recovery profitable. Examination of this recovered oil showed its characteristics to be practically identical with the oil distilled directly from the herb.

VARIETIES.

During the many years that lemon grass has been cultivated a great variety of forms of the plant has been developed. Some years ago an attempt was made to divide the old species into two separate species, basing the descriptions partially on the character of the oil secured from the two sorts. In the essential-oil trade it long has been recognized that there is a wide difference in the characteristics of lemon-grass oils from different regions. It is not the purpose of this paper, however, to discuss any questions of systematic relationship or nomenclature of the plant, but since a wide difference has been found in the commercial value of the strains under experimental cultivation, a brief discussion of these will be of interest to the prospective grower.

During the course of the experiments, plants were obtained from a number of sources, and altogether 13 different strains have been tested. Following are the sources of the various strains:

1. Secured from a nursery in Florida. The original stock was from Havana.
2. A local form sold in the Florida nursery trade.
3. Isle of Pines.
4. Porto Rico.
5. Cochin China.
6. Ceylon.
7. Mexico.
8. India.
9. India.

10, 11, and 12. Origin unknown

13. Ceylon.

These 13 strains fall into the following classes as regards growth characteristics:

(1) The West Indian type, represented by Nos. 1, 2, 3, and 4. The plants are 2½ to 3 feet high, with lax, drooping leaves and of light color.

(2) The East Indian type, represented by Nos. 5, 8, and 9. The plants are 3½ to 4 feet high and erect. The leaves are rather erect and more scabrous than the West Indian form.

(3) The Mexican form, represented by No. 7. This is a weak form, very drooping in habit, with lax leaves and very light in color.

No. 6 has the typical West Indian appearance, but is markedly different in oil yield. No. 13 has the typical East Indian appearance, except the color, which is very light, almost yellowish. Nos. 10, 11, and 12 are of the approved East Indian type.

Table III shows the variations in the yield of oil and the citral content of the oil from these various types for the season of 1915.

TABLE III.—*Yield and citral content of lemon-grass oils distilled from the various plants under cultivation in 1915.*

Variety.	Yield of oil.	Citral content of the oil.	Variety.	Yield of oil.	Citral content of the oil.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
No. 1	0.24	80	No. 9	0.20	76
No. 5	.27	70	No. 10	.23	80
No. 6	.16	73	No. 11	.28	80
No. 7	.23	72	No. 12	.29	81
No. 8	.15	79	No. 13	.12	85

It has been found year by year that there is considerable variation in both the yield of oil and the citral content, yet the figures given in Table III may be taken as representative of the varieties mentioned. It will be noted that the Ceylon forms, Nos. 6 and 13, are very low in oil yield, and the same is true of No. 8, from India.

Both the yield of oil and the citral content of the oil have been found to be affected to a considerable degree by the type of soil on which the plants are grown. Therefore, before selecting a variety for commercial planting, tests should be made to determine which variety will give the highest yield of oil per acre and the highest citral content on the land to be used. The vigor of the plants should also be considered, since there seems to be a difference in soil requirements among the varieties tested.

FACTORS AFFECTING THE YIELD OF LEMON-GRASS OIL.

Soil conditions.—In order to determine the effect of soil conditions on the yield of lemon-grass oil, tests were made in 1908 with the West Indian variety, No. 1, on soils containing various degrees of moisture. On light sandy soil of the high hammock type the yield of oil was 0.31 per cent, and on moist bottom land 0.27 per cent. Another test on sandy high pine land in a different location gave an oil yield of 0.35 per cent, and on moist land near the lake 0.28 per cent. Further tests with this variety under other conditions of soil moisture gave results which were also much in favor of the sandier and better drained land. In 1915 the plat devoted to the Ceylon variety, No. 6, showed a higher yield of oil from the plants grown on the high, well-drained, sandy soil than from the part of the plat which contained slightly more moisture, 0.16 per cent being obtained from the former and only 0.11 per cent from the latter. Similar results were secured in 1914 with varieties Nos. 5, 8, and 9.

The evidence thus far available indicates that for all the forms of lemon grass tested, a heavy growth of herb with high oil content is to be expected on light, well-drained soil of the high pine type.

Time of harvest.—Since lemon grass is a perennial crop and two or three cuttings can be made each year, it is of interest to note the difference in yield of oil secured from the plants at each harvest. In Table IV are given the results obtained from each of two harvests for various years.

TABLE IV.—*Yield of lemon-grass oil distilled from plants harvested at two different times of the year.*

Year and plants harvested.	Yield of oil.		Year and plants harvested.	Yield of oil.	
	First harvest.	Second harvest.		First harvest.	Second harvest.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1908.			1914—Continued.		
First plat	0.31	0.33	No. 8	0.12	0.38
Second plat	.40	.48	No. 9	.24	.36
Third plat	.20	.35	1915.		
1912.			No. 1	.27	.26
No. 1	.40	.36	No. 8	.11	.11
No. 8	.28	.46	No. 9	.19	.17
1914.			No. 10	.23	.47
No. 1	.37	.50	No. 11	.28	.40
No. 5	.34	.35	No. 12	.29	.31
No. 6	.16	.20	No. 13	.12	.27

These results show that in general the percentage of oil is higher in the second cutting. In the first year of planting, however, the quantity of herb obtained in the second cutting is much less than that from the first cutting; consequently, the acre yield of oil in the first year would be greater from the first cutting rather than from the second.

FACTORS AFFECTING THE CITRAL CONTENT OF LEMON-GRASS OIL.

Closeness of cutting the plants.—Experiments conducted with variety No. 1, grown on very light sandy soil, showed that the citral content was highest in the part of the plant nearest the ground. Large plants divided into three portions yielded, on distillation, oil with citral content as follows: Upper portion, 70 per cent; middle portion, 78 per cent; and lowest portion, 82 per cent. A similar test made with variety No. 5 divided into only two portions yielded oil with citral content in favor of the lower portion, as follows: Upper portion, 74 per cent; lower portion, 76 per cent. These results show that the closest cutting which gives a profitable yield of oil also produces a better quality of oil.

Soil moisture.—Plants of variety No. 1, grown on soils having varying degrees of moisture, yielded oil with citral content as follows: On dry sandy soil, 75 per cent citral; on slightly moist sandy loam, 68 per cent; and on moist loam near the lake, 66 per cent. Further tests with other varieties on different types of soil have given similar results. This would indicate that high citral content can be secured only from plants grown on very well drained soil.

Time of harvest.—Although the citral content of the oil does not appear to be greatly affected by the time of harvest, the results indicate that of the two harvests each year the oil distilled from plants of the first harvest contains the greater quantity of citral. Data covering a number of years are given in Table V.

TABLE V.—*Citral content of lemon-grass oil distilled from plants harvested at two different times of the year.*

Year and plants harvested.	Citral content of oil.		Year and plants harvested.	Citral content of oil.	
	First harvest.	Second harvest.		First harvest.	Second harvest.
1908.	*Per cent.*	*Per cent.*	1914—Continued.	*Per cent.*	*Per cent.*
First plat	72	74	No. 8	81	72
Second plat	74	72	No. 9	75	59
Third plat	75	72	1915.		
1912.			No. 5	70	68
No. 1	76	78	No. 6	73	71
No. 8	78	76	No. 8	77	64
1914.			No. 9	78	70
No. 1	78	....	No. 10	80	74
No. 5	78	76	No. 11	80	82
No. 6	77	79	No. 12	81	80
			No. 13	85	82

SOLUBILITY OF LEMON-GRASS OIL IN ALCOHOL.

For many years it was considered that good lemon-grass oil should be soluble in clear solution in three volumes of 70 per cent alcohol, and this was the test applied before the method of citral determination was in general use. It served a useful purpose, however, inasmuch as certain adulterations which had become quite general could thus be detected, but at the present time, when the valuation of the oil is entirely on the basis of the citral content, it is difficult to understand the reason for the continued use of the solubility test. It has been shown repeatedly that in many parts of the world pure lemon-grass oil does not pass the solubility test, especially after it has been stored for several months. This has been true of most of the samples of the oils produced in the Western Hemisphere, so that West Indian lemon-grass oil has come to be a synonym for insoluble oil. This discrimination has kept out of the market many West Indian oils of very high citral content.

There has been much discussion regarding the factors which affect the solubility of the oil, it having been contended that the length of time of distillation is the controlling factor. In order to secure data upon this point the following tests were made: In 1914, 158 pounds of the freshly cut plants were distilled with steam and the oil drawn off in fractions at intervals of 45 and 60 minutes, respectively. The first fraction represented a yield of oil of 0.28 per cent, the citral content of the oil being 80 per cent, while the second fraction represented a yield of 0.04 per cent of oil, with a citral content of 85 per cent. When first distilled the first fraction gave a slightly cloudy solution with three volumes of 70 per cent alcohol, but after two months it gave a very cloudy solution in all volumes of 70 per cent alcohol. The second fraction was soluble with clear solution in three volumes of 70 per cent alcohol, showing no sign of change after two months. Another sample of 203 pounds of the fresh plants distilled with steam and the oil drawn off in fractions at intervals of 15, 15, 20, and 40 minutes, respectively, gave the results shown in Table VI.

TABLE VI.—*Citral content and solubility in 70 per cent alcohol of various fractions of lemon-grass oil.*

Fractions.	Yield of oil.	Citral content of oil.	Solubility in 70 per cent alcohol.
	Per cent.	*Per cent.*	
First 15 minutes	0.21	39	Soluble with very cloudy solution in two volumes and over.
15 to 30 minutes	.21	74	Soluble in clear solution in two volumes and over.
30 to 50 minutes	.05	82	Do.
50 to 90 minutes	.01	80	Do.

From the results shown in Table VI it is evident that complete extraction of the oil gives a product of greater solubility and higher citral content.

The oils produced in Florida from all varieties of the plant have passed the solubility test when first distilled, but after storing for three months all have become insoluble. At the present time there is a decided tendency to disregard the solubility test, and no difficulty has been encountered in selling the Florida oils at a good price when the citral content was 70 per cent or more.

COMMERCIAL POSSIBILITIES.

The consumption of lemon-grass oil in the United States for the manufacture of ionone and for perfumery purposes is continually increasing, and it is believed that the demand is sufficient to warrant an attempt to grow the plant for the commercial production of the oil in such parts of the country as possess the proper climatic requirements. Tests on acre plats have been made to determine the cost of production, the best methods of distilling the oil, and the quality of the product. Samples of the oil produced have been sold on the market at the prices prevailing for the better grades of imported oil, and it seems possible to produce the oil commercially at a fair profit.

From the experiments made thus far the following estimates are given of the cost of production and the returns that may be expected for this crop under average conditions:

EXPENDITURES.

First year (per acre):	
Preparing the land	$3.00
Planting	2.00
Fertilizers	8.00
Cultivation	2.00
Harvesting and distilling	5.00
Total expenditures, first year	20.00
Succeeding years (per acre):	
Cultivation	1.00
Fertilizers	8.00
Harvesting and distilling	8.00
Total expenditures, second year and succeeding years	17.00

RETURNS.

First year: 25 pounds of oil per acre, at 80 cents	20.00
Succeeding years: 35 pounds of oil per acre, at 80 cents	28.00

In these statements no allowance is made for such charges as taxes, insurance, interest, or depreciation of outfit. It is doubtful whether the production of lemon-grass oil would be profitable if all overhead charges were placed against this crop alone, since the distilling plant would be in use only a few weeks in a year. However, if grown in connection with other volatile-oil plants, so that a long distilling season would be secured, it is believed that this crop will yield returns comparing favorably with other crops grown on the same type of land.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 443

Contribution from the Bureau of Entomology,
L. O. HOWARD, Chief.

Washington, D. C. ▲ September 21, 1916

THE NEW MEXICO RANGE CATERPILLAR AND ITS CONTROL.[1]

By V. L. WILDERMUTH, *Entomological Assistant*, and D. J. CAFFREY, *Scientific Assistant, Cereal and Forage Insect Investigations.*

CONTENTS.

	Page.
Introduction	1
General description of the range caterpillar	2
Where the range caterpillar occurs	3
Its economic importance and great abundance	3
Crops and grasses attacked	4
Character of the injury	4
Life history of the range caterpillar	6
Natural enemies of the range caterpillar	8
A wilt or rot disease	9
Destruction by hail	9
History of the range caterpillar	10
Control measures	11

INTRODUCTION.

The New Mexico range caterpillar[2] (fig. 1) is regarded as a serious pest by the stockmen and farmers of eastern and southern New Mexico. It devastates large areas of range pasture and at one time threatened to destroy the live-stock industry over an area of 30,000 square miles. Formerly it fed only upon the range grasses, but of late has changed its feeding habits and now attacks many cultivated crops as well. The present destructive abundance of the pest is probably due to the fact that the natural enemies, in the form of parasitic and predacious insects, birds, and small mammals, were reduced in numbers through some severe climatic condition which, however, did not destroy the cater-

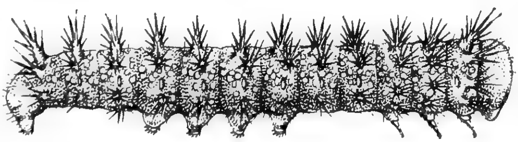

FIG. 1.—The New Mexico range caterpillar: Larva, fourth stage. Much enlarged. (C. N. Ainslie.)

[1] The purpose of this bulletin is to place before the stockmen and farmers of the Southwest the results of investigations carried on during the past three years concerning the control of the New Mexico range caterpillar.

[2] *Hemileuca oliviae* Ckll.; order Lepidoptera, family Saturniidae.

pillar. Without these natural checks the caterpillar multiplied and became destructively numerous. At the present time the introduced and native natural enemies are apparently reducing its numbers and it is hoped that it will soon cease to be a menace.

GENERAL DESCRIPTION OF THE RANGE CATERPILLAR.

The newly hatched caterpillars (fig. 2) are one-fourth of an inch long, dark brown or black in color, covered with fine prickles or spines, and may be seen during the cooler parts of the day feeding in groups. When not feeding, or during cold or wet weather, the

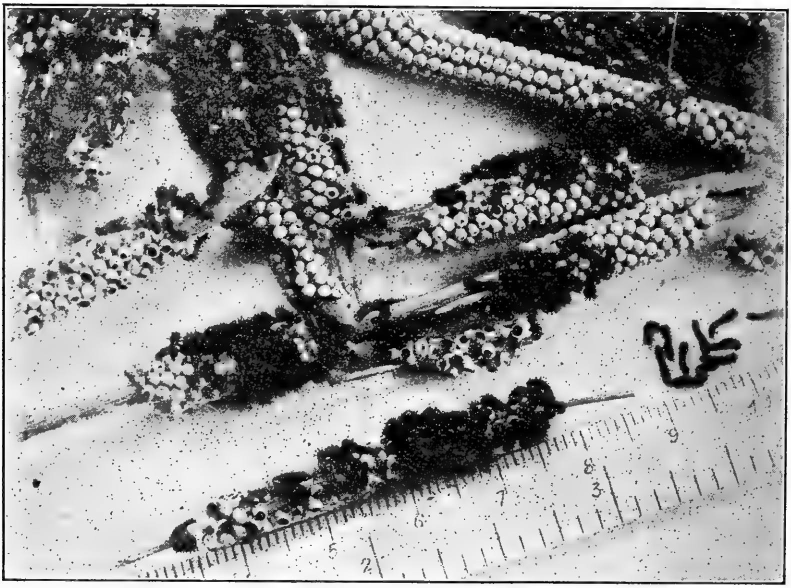

FIG. 2.—Hatching of the eggs of the New Mexico range caterpillar. Size of larvæ indicated by metric rule beneath. (C. N. Ainslie.)

small caterpillars (fig. 3) ascend a grass or weed stem and twine themselves together in a tight ball, for mutual warmth and protection against cold or rain. When in this position they are conspicuous objects upon the prairie. These small caterpillars feed upon their various food plants, growing rapidly larger, and as this occurs they separate from one another, and generally feed alone. In this process of growth the caterpillar "sheds its skin," or molts, five times, after each molt becoming larger and of a different color, gradually changing from the dark brown or black of the newly hatched caterpillars to a uniform light brown, then to a light brown streaked with yellow, and finally the full-grown caterpillars appear, yellow in color, with faint black markings. These full-grown yellowish caterpillars are from 2 to 3 inches long and as thick as a man's little finger, being covered with clusters of sharp, poisonous spines. They remain in this stage about four weeks, and, owing to their large size, greediness, and great numbers, do their greatest damage at this time by devouring, or rendering unfit for grazing, most of the range grasses, and certain cultivated crops to a more limited degree, over large areas.

WHERE THE RANGE CATERPILLAR OCCURS.

At the present time the range caterpillar is known to occur in the northeastern and south-central portions of New Mexico, with a scattering infestation along the adjoining "Panhandle" of Texas. During the season of 1915 small colonies were found at Duran and Corona, in southern New Mexico. The parent moths have been found outside the limits mentioned, but in these localities no caterpillars have ever been discovered, although the surrounding country has been searched each year for evidence of their presence. It seems possible that this pest may eventually be found far to the southward of its present known limits, but the insect is now of great economic importance only in the northeastern corner of New Mexico, in the counties of San Miguel, Taos, Mora, Colfax, and Union.

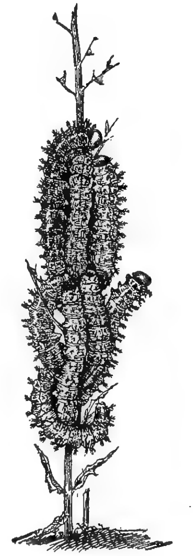

FIG. 3.—The New Mexico range caterpillar: Larvæ clustered on weed stem, to avoid the heated surface of the ground. (C. N. Ainslie.)

ITS ECONOMIC IMPORTANCE AND GREAT ABUNDANCE.

In many parts of the section just mentioned these range caterpillars, or "grass-worms," as they are popularly known, constitute a great menace to successful stock raising and farming. When the present investigations began, many stockmen and farmers were of the opinion that on account of the ravages of this insect it would be necessary to abandon stock raising in that part of New Mexico, which, as has been stated, includes an area of approximately 30,000 square miles, or about the area of Maine.

Owing to the constantly decreasing area devoted to stock raising, the economic importance of this caterpillar can not be overestimated.

The great abundance of these caterpillars should be taken into consideration in estimating the damage caused by the insect. In 1913 a total of 300 full-grown caterpillars were counted feeding upon an average square rod of pasture, 6 miles northeast of Las Vegas. This is at the rate of 30,720,000 of these large caterpillars per square mile. Many square miles in this section were similarly infested. The caterpillar is commonly found in numbers of from 100 to 200 to the square rod over all of the infested section. It is plainly evident that the tremendous abundance of the pest constitutes a grave menace to any crops attacked.

CROPS AND GRASSES ATTACKED.

The range caterpillar devours the range grasses down to, but not including, their roots. It feeds upon all the grama grasses, bunch grass, foxtail, side oats, wild rye, blue-joint, mesquite grass, buffalo grass, and even bluegrass on lawns. About 40 different kinds of grasses are included in the determined list of food plants of this insect.

One of the most important developments noted during the past two years is that of the apparent change of the food habits of the range caterpillar. In many instances, in addition to its damage to the range grasses, it has seriously injured cultivated grains and forage crops, including millet of various kinds, wheat, oats, barley, milo maize, Sudan grass, and, to a slight extent, corn and alfalfa. Of the cultivated crops, millet has appeared to suffer the most from attacks of this caterpillar. The damage to such crops has usually occurred where isolated farms were surrounded by infested range pastures. As the range country of New Mexico is rapidly becoming a dry-farming and irrigated agricultural district, it is evident that the range caterpillar, unless checked, is likely to become a serious pest to cultivated crops, and therefore of as much importance to farmers as to stockmen. However, it is at present primarily destructive to the range pastures.

CHARACTER OF THE INJURY.

The range caterpillar injures the crops in two ways: First, by eating the range plants down to the roots, over large areas, and in the case of cultivated crops by devouring the leaves; second, by poisoning the uneaten plants with the caterpillar spines, which it sheds in crawling from place to place or during the process of molting.

INJURY CAUSED BY PLANT FEEDING.

The injury caused by the range caterpillar in feeding upon various plants is the more important of the two, as it deprives the grazing stock of food and renders such cultivated crops as millet and Sudan grass unfit for forage. The greatest amount of damage is done during July and August, although some destructive feeding takes place during late June and early September. When the caterpillars are very numerous the range pastures for many miles will have the appearance of having been clipped by a lawn mower. Under these conditions many of the caterpillars die through lack of sufficient food to enable them to complete their growth.

In cultivated crops the caterpillars devour the leaves and, in rare instances, the upper and tender portions of the stem.

The caterpillars are very greedy and wasteful feeders, often eating only a small part of each plant destroyed. Frequently they will bite through a plant stem several inches below its top and then eat from this point down to the junction of stem and roots, leaving the upper part of the plant as waste. They are equipped with large, powerful jaws and eat a tremendous amount of plant matter each

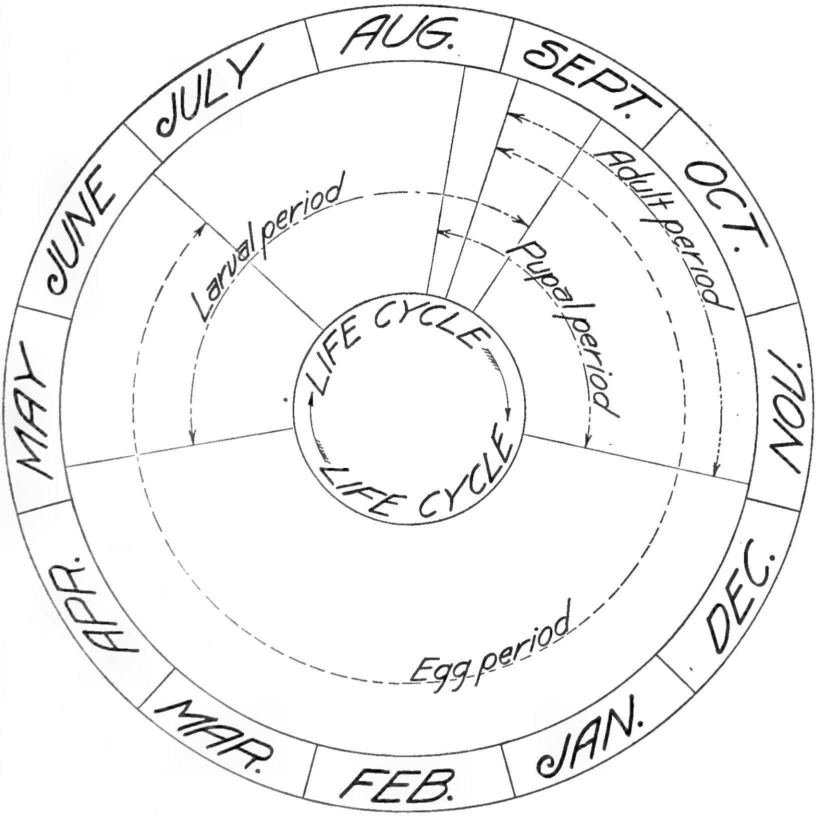

FIG. 4.—Diagram illustrating life cycle of the New Mexico range caterpillar. (Original.)

day. Much of this food is not fully digested, but passes through the caterpillar and is voided in an apparently slightly changed condition. Oftentimes it appears that the caterpillars eat from habit rather than necessity.

INJURY CAUSED BY POISONING UNEATEN PLANTS.

When partly grown the range caterpillars develop poisonous spines, probably as a protection against birds or insect-eating mammals. In crawling from place to place, or during the process of molting, these spines (see fig. 1) become scattered through the uneaten plants.

Upon coming in contact with the tender portions of the human skin, such spines cause at first an intense local irritation or smarting, which later results in a swollen and itching condition of the affected parts, resembling that caused by the sting of a wasp. It is possible that the same thing happens to the mouth of an animal feeding upon this grass, and that after one experience the plants are left untouched. At least the cattle seem to avoid grasses so affected. For this reason many areas of range pasture not actually destroyed by the range caterpillar are rendered unfit for grazing purposes.

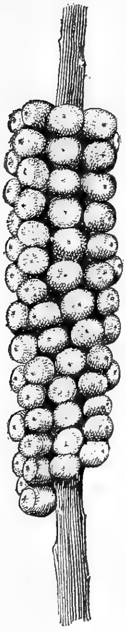

FIG. 5.—Egg mass of New Mexico range caterpillar on weed stem. Enlarged. (C. N. Ainslie.)

FIG. 6.—The New Mexico range caterpillar: Female moth in characteristic resting attitude. Enlarged. (C. N. Ainslie.)

LIFE HISTORY.

During its life (see fig. 4) the range caterpillar passes through four stages—first the egg, then the caterpillar, next the pupal or "spun-up" stage, and, lastly, that of the moth or parent.

Egg stage.—The eggs (fig. 5) are deposited by the parent moths (fig. 6) during the months of September, October, and November, in cylinder-shaped clusters, about the diameter of an ordinary lead pencil, encircling grass and weed stems. These egg clusters contain from 50 to 175 eggs, are pearl-white in color, and from their size and position are frequently mistaken for bunches of weed seeds. The individual eggs are very thick-shelled and able to withstand the winter weather conditions in New Mexico.

FIG. 7.—The New Mexico range caterpillar: Pupa, side view. Enlarged. (C. N. Ainslie.)

Caterpillar stage.—The caterpillars (fig. 2) hatch from the eggs as a rule in May or early June, the time depending upon moisture conditions. A certain amount of moisture appears to be necessary for hatching the eggs, temperature being of less importance. By late August or during September the caterpillars have completed their growth and are ready to enter the "spun-up" or pupal stage.

Pupal stage.—In entering its pupal or resting stage (fig. 7) the full-grown caterpillar draws the stems and leaf blades of any weed or grass plant together (fig. 8), and inside this foundation spins a rough, netlike inclosure or cocoon of yellow silk.

Inside this cocoon the pupa is formed. The pupa is dark brown in color, more or less cone-shaped, and from 1 to $1\frac{1}{2}$ inches long. It is this process of "spinning up" that causes the matted and distorted appearance of the range plants from late August to the end of the year. The pupal period lasts for a month or six weeks and then the moth comes forth.

Moth, or parent insect.—The moth (see figs. 6 and 9), or parent, when freshly emerged bears only short, stubby wings, and may be seen during the early part of the day clinging to a grass or weed stem situated near its former cocoon. After a few hours the wings become fully developed and the moth takes flight. Mating occurs very soon after emergence from the pupa, and within 24 hours the female deposits her eggs for next year's brood of range caterpillars, after which she usually dies very quickly. In the moth stage this insect does not consume any solid food. Most of the moths emerge and deposit their eggs during the period between September 10 and November 15. They are most active just before sunset and are often so numerous as to give the impression of a snowstorm.

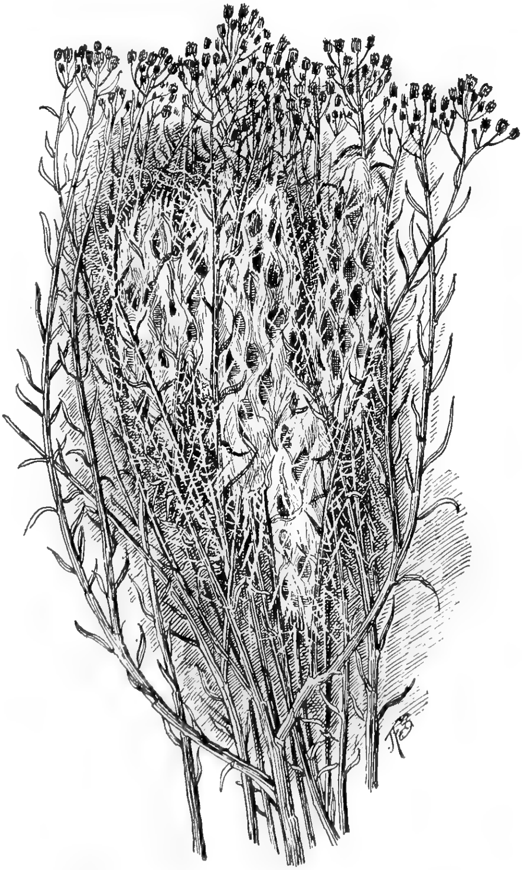

FIG. 8.—The New Mexico range caterpillar: A characteristic mass of cocoons in a single plant of Gutierrezia. Reduced. (C. N. Ainslie.)

The male and female moths differ in color and size. The male moth measures about 2 inches from tip to tip of the wings; his wings are white or light gray, and his body is covered with long, brick-red hairs. The female moth is larger than the male, being generally $2\frac{1}{2}$ to 3 inches from tip to tip of the wings; her wings are reddish gray or dark brown and her robust body is dark reddish brown with white stripes on the lower side.

NATURAL ENEMIES OF THE RANGE CATERPILLAR.

Several kinds of natural enemies native to New Mexico are destroying the range caterpillar. To help these native forms, other kinds of natural enemies have been introduced.

NATIVE NATURAL ENEMIES.

A small percentage of range caterpillar eggs is destroyed by a four-winged, wasplike internal parasite. Two kinds of two-winged flies resembling house flies or blowflies lay their eggs upon the caterpillars, and the maggots hatching from them act as internal parasites, devouring the flesh and "insides" of the caterpillars. One of these flies is illustrated in figure 10. Furthermore, three kinds of wasplike internal parasites, one of which is shown in figure 11, have been found to destroy the pupæ. The effectiveness of such parasites in different localities varies from less than 1 to as much as 75 per cent of the caterpillars and pupæ present.

FIG. 9.—Male moths of the New Mexico range caterpillar resting during the day on stem of wild sunflower. (C. N. Ainslie.)

Skunks eat great numbers of range caterpillar pupæ and have been the means of practically exterminating the pest over certain areas. During the autumn season about 85 per cent of the food of the skunk, in the infested region, consists of these pupæ. This animal is very valuable as a destroyer of insects.

Badgers, coyotes, mice, and robins also feed upon the range caterpillar in its various stages. Several kinds of large ground beetles, some of the large ants, and robber flies prey upon the pest.

In some localities from 10 to 50 per cent of newly deposited eggs are destroyed by two different kinds of camel crickets.

INTRODUCED NATURAL ENEMIES.

Natural insect enemies, similar to those mentioned above, have been introduced into New Mexico from Massachusetts, Indiana, Kansas, Missouri, and California in an attempt to aid the native natural enemies already present. Some of these have established themselves in New Mexico and are at work helping to destroy the range caterpillar. None of these introduced insects, under any possible circumstances, could become injurious to crops.

Among the most important of these insects which have established themselves in New Mexico are three kinds of large ground beetles introduced from Massachusetts. One of these is illustrated in figure 12. Although only the above-mentioned insect enemies are known to be at work, additional natural enemies have been introduced to work upon the range caterpillar, and it is expected that they will soon make their presence felt.

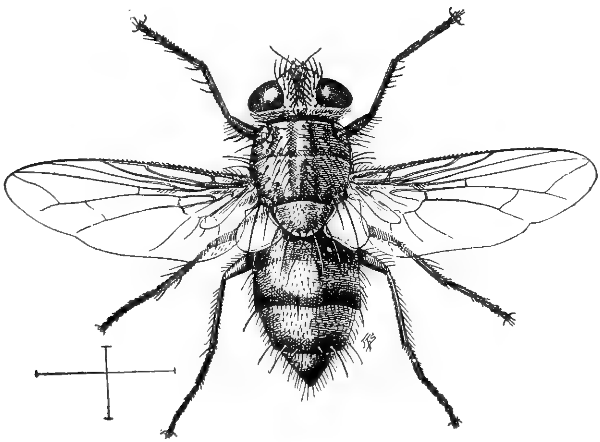

FIG. 10.—*Tachina mella,* a fly which is parasitic on the range caterpillar: Adult. Enlarged. (C. N. Ainslie.)

A WILT OR ROT DISEASE.

A "wilt" or rot disease in favorable seasons kills many range caterpillars during the late summer. This happens at rare intervals during unusually wet weather, but owing to the semiarid conditions of this region the disease can not be depended upon to hold the range caterpillar in check.

DESTRUCTION BY HAIL.

Hailstorms often kill many full-grown caterpillars during August and September.

HISTORY OF THE RANGE CATERPILLAR.

As a result of complaints received from the stockmen of northeastern New Mexico concerning the ravages of the range caterpillar, a preliminary investigation was made during the period 1908 to 1912.[1]

It appears that no records exist of damage by this insect until about 1904—that is, five years previous to the beginning of the original investigations. There is no doubt, however, that the range caterpillar has been present in limited numbers in the section for many years, and probably for centuries. Taking these facts into consideration, it is probable that just previous to the date mentioned above some severe and unusual climatic condition caused the death of most

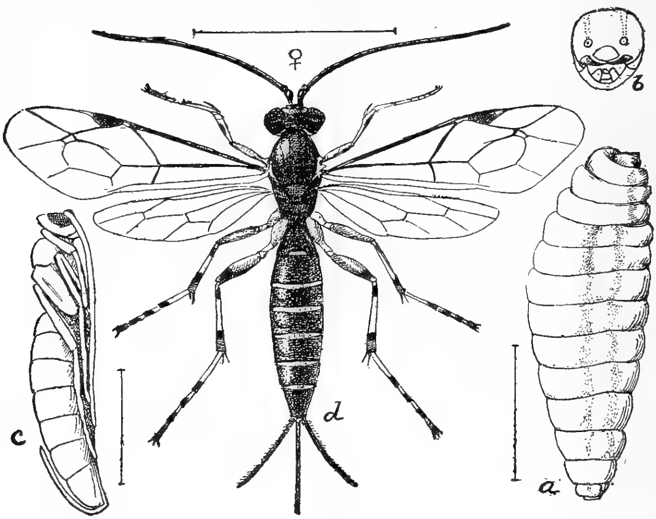

FIG. 11.—*Pimpla conquisitor*, a parasite of the range caterpillar: *a*, Larva; *b*, head of same; *c*, pupa; *d*, adult female. Enlarged. (*d*, C. N. Ainslie; *a*, *b*, *c*, redrawn from 4th Rpt. U. S. Ent. Comm.)

of the natural enemies of the range caterpillar but allowed the pest to survive, and in consequence to multiply rapidly and injure the range. These unusual climatic conditions might have been in the nature of a severe, long drought, or it might have been a mild, warm period in midwinter, followed by a rapid drop in temperature, conditions which occur in the plateau regions of New Mexico.

In 1913 a camp was established in the midst of badly infested range pastures on the open range 6 miles east of Koehler, N. Mex. To this camp natural enemies of the range caterpillar were brought from various parts of the country. Experiments carried on under temporary structures demonstrated that some of these natural enemies were effective against the pest and were capable of existing

[1] Ainslie, C. N. The New Mexico Range Caterpillar. U. S. Dept. Agr. Bur. Ent. Bul. 85, pt. 5, pp. 59–96, figs. 32–53, pls. 3, 4. 1910.

under New Mexico conditions. These were therefore liberated on the range.

After two years at this camp it became evident that permanent quarters were necessary, so a laboratory was established at Maxwell, N. Mex., where work against the range caterpillar and other cereal and forage-crop insects is now being carried on.

At the present time the native natural enemies are beginning to assert themselves again, and with the help of the introduced enemies it is hoped that the range caterpillar will soon be reduced to a point where it will cease to menace the stockmen and farmers of the Southwest.

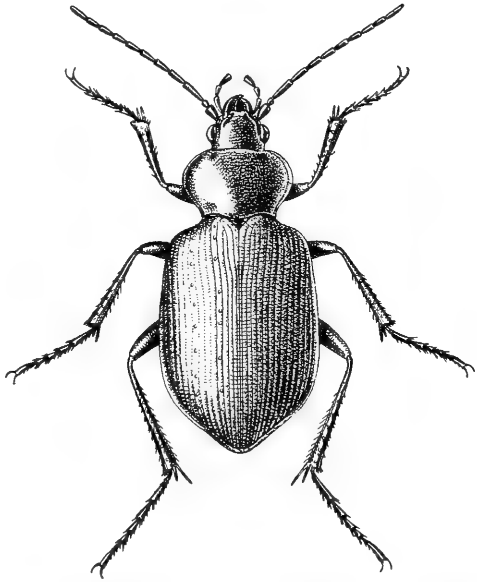

FIG. 12.—A predatory ground beetle, *Calosoma sycophanta*, introduced into New Mexico from Massachusetts to help in the destruction of the range caterpillar. About twice natural size. (Howard.)

CONTROL MEASURES.

Mechanical measures, such as burning the range, rolling the ground, and brush dragging have been suggested as a possible means of artificially controlling the range caterpillar. The pasturing of turkeys and sheep has also been proposed as a means of control.

Burning the range.—Burning the range to destroy the range caterpillar has been tried out on several occasions, but has not proved successful on a large scale because of the lack of sufficient vegetation on most of the range to support a hot running fire. Under certain favorable circumstances the winter burning of restricted areas has proved of great benefit in destroying the overwintering egg clusters. Cultivated areas usually may be protected by winter burning the surrounding egg-bearing grass, weeds, or other vegetation. However, such burning destroys the grass crop for that year, and unless carefully conducted may result in the burning of buildings or timber in the vicinity.

Rolling the ground and brush dragging.—Rolling the ground with a heavy corrugated iron roller proved expensive and killed only a small percentage of the caterpillars present, on account of the tufted or uneven condition of the surface. Brush-dragging the small caterpillars gave similar results.

Use of sheep and turkeys.—The pasturing of sheep might prove effective in killing range caterpillars or pupæ over small areas, but this method would not be practical on the vast expanse of the cattle ranges. Turkeys kept in confinement refused to eat the range caterpillar, and it therefore seems probable that they would not accept them as food on the range.

General considerations.—In any method for destroying the range caterpillar, the low value of the range land must be taken into consideration. This land sells for $5 or $10 per acre and rents at from 2 to 10 cents per acre. It will thus be seen that none of the foregoing methods of artificial control are practical on range land. Thus the introduction of natural enemies remains as probably the best solution of the problem.

Protection of cereal crops.—When this pest is found attacking cultivated cereal crops, such as corn, sorghum, or kafir, it can be controlled by spraying these crops with a solution of powdered arsenate of lead, 1 pound to 50 gallons of water. But crops so treated should not be pastured off or fed to stock *until after heavy rains have fallen,* and at least 30 days should elapse between the time of spraying and the use of such crops as forage.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 444

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER November 25, 1916

FALSE BLOSSOM OF THE CULTIVATED CRANBERRY.

By C. L. Shear, *Pathologist, Fruit-Disease Investigations.*

CONTENTS.

	Page.		Page.
Introduction	1	Cause	4
Description of false blossom	1	Control	5
Origin and distribution	3	Summary	5
Economic importance	4	Literature cited	7

INTRODUCTION.

For a number of years past an abnormal development of vines of the cranberry (*Oxycoccus macrocarpus*) has caused considerable loss in cranberry marshes, especially in the district about Grand Rapids, Wis. The trouble is commonly called false blossom by the growers. Since this term is so generally used in Wisconsin and is somewhat applicable to the disease, it is probably best to adopt it as the common name. It should be explained, however, that a disease of an entirely different nature, caused by *Exobasidium oxycocci* Rost., has received the same name among Massachusetts growers. The name rose-bloom is proposed for this latter disease.

DESCRIPTION OF FALSE BLOSSOM.

The disease under consideration produces as one of its most conspicuous features a malformation or metamorphy of the floral organs. It was briefly described by the writer (10)[1] in 1911. In the simplest form of the trouble the flower pedicels become more or less erect instead of drooping and the calyx lobes become enlarged, greenish, and somewhat foliaceous. The petals become shortened, broadened,

[1] The figures in parentheses refer to "Literature cited" at the end of the paper.

NOTE.—This bulletin is of interest to plant pathologists and to cranberry growers, especially in the States of Massachusetts, New Jersey, Wisconsin, and the coastal regions of Oregon and Washington.

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and slightly reddish or greenish in color, as shown in Plate I, figure 2, *b* and *c*. The stamens and pistil are more or less aborted and malformed and no fruit is produced. Plate I, figure 1, shows normal flowers for comparison.

All intermediate gradations of phyllody can usually be found among diseased vines, from the simple form, in which there is only a shortening and thickening of the parts of the perianth, to cases in which the entire flower is replaced by a short branch with small leaves, as shown in Plate II, figure 1, *c*, *d*, and *e*.

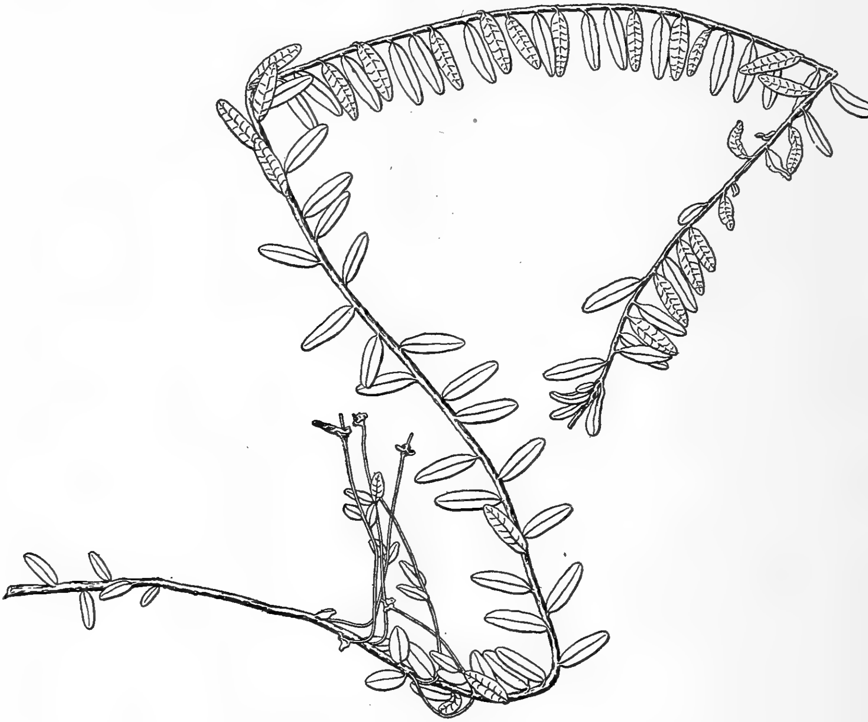


FIG. 1.—A cranberry plant in which the terminal bud has developed into a runner instead of a fruiting bud.

Plate III shows a condition in which the different floral organs are represented by whorls of green, leaflike structures on the prolonged axes. Besides the transformation of the floral organs, other abnormalities of growth are usually found. Plate IV shows details of a malformed flower and various conditions of development of leaflike bodies in whorls on the prolonged floral axis. Affected plants have a great tendency to develop lateral branches from the usually latent axillary buds situated on the vine below the fruit bud, as shown in figure 1. The branches are slender and weak and fail to produce normal flowers or fruit. They give the plant a kind of witches'-broom appearance. In some instances the end of the flowering shoot, instead of forming a fruit bud for the next season, as is the case in normal plants, continues to grow and produces a long, slender runner, as shown in figure 2. Cranberry plants in bogs where this malformation occurs generally show an excessive vegetative growth, usually forming a deep, dense mass of vines.

In their dormant condition the terminal buds are frequently enlarged and abnormal and die during the winter. Under some conditions the plants produce few runners.

FIG. 2.—A cranberry plant in which the normally dormant axillary buds have developed into shoots.

ORIGIN AND DISTRIBUTION.

All the data at hand seem to indicate that this disease first appeared in Wisconsin. Cases of phyllody have been found in Massachusetts, New Jersey, Oregon, and Washington, but most cases appear to be traceable to vines obtained from Wisconsin. No printed reference to this disease has been found by the writer previous to his brief mention of it (9) in 1908. The disease has, however, undoubtedly been present in Wisconsin for many years.

The first cases of the disease discovered in Massachusetts were examined by Dr. H. J. Franklin and the writer in 1914 and have been reported by Franklin (3). Affected vines were observed in five different bogs. In four cases the vines were of the variety known as Metallic Bell, which had been obtained from Wisconsin. In the fifth case the variety was unknown, but this also had come from Wisconsin. These vines had been planted about 10 years previously. The next year, 1915, the writer's attention was called to the occurrence of this disease in New Jersey. In this case the plants were of the Jumbo variety obtained from Wisconsin and planted several years previously.[1] In both Massachusetts and New Jersey a few scattered vines showing the disease have been found in plantings of eastern varieties in the same bog, but whether these diseased vines are really eastern plants or have arisen from Wisconsin cuttings is very difficult to determine, since plants affected with false blossom rarely develop normal fruit. This has raised the question of the possible infectious nature of the disease.

[1] Since this was written the disease has been found in other bogs in New Jersey under such conditions as to suggest that the disease may have developed there independently.

ECONOMIC IMPORTANCE.

This disease is an important factor in reducing the crop of cranberries in Wisconsin. In some bogs one-half of the crop may be lost on this account, as affected vines rarely produce any good fruit. Fortunately, in Massachusetts, New Jersey, and on the Pacific coast the disease up to the present time is confined to very small areas. It is very important, therefore, to avoid the introduction of diseased vines in new plantings.

CAUSE.

At present the cause of this pathological condition is uncertain. Careful examination and study of many specimens in the field and laboratory have failed to give any evidence that insects or fungi cause the trouble, and the writer has come to believe, from all the evidence at present available, that it is primarily due to some serious disturbance of the nutritive functions of the plant. Goebel (4) says: "In like manner there can be no doubt that the phyllody of flowers, a favorite domain of teratology, is a symptom of disease; it is a misbirth, the cause of which we do not know in most cases." Similar effects, such as chloranthy, as Peyritsch (8) has shown, may be induced by aphides. In other cases it may be assumed that the power of producing reproductive organs has been enfeebled, while the vegetative growth has been abnormally stimulated through the nutritive conditions.

Beijerinck (1 and 2) assumed the existence of certain growth enzyms which caused the formation of normal organs. In case of the transformation of organs, according to his theory, one growth enzym must replace another or be formed instead of it.

In the case of the cranberry it seems possible that this striking metamorphy is due to some serious disturbance of the nutrition of the plant. A similar opinion was also expressed by Jones and Shear (5) as the result of a joint field study of the disease. Mr. Malde (6), who has observed this trouble for many years in Wisconsin, says:

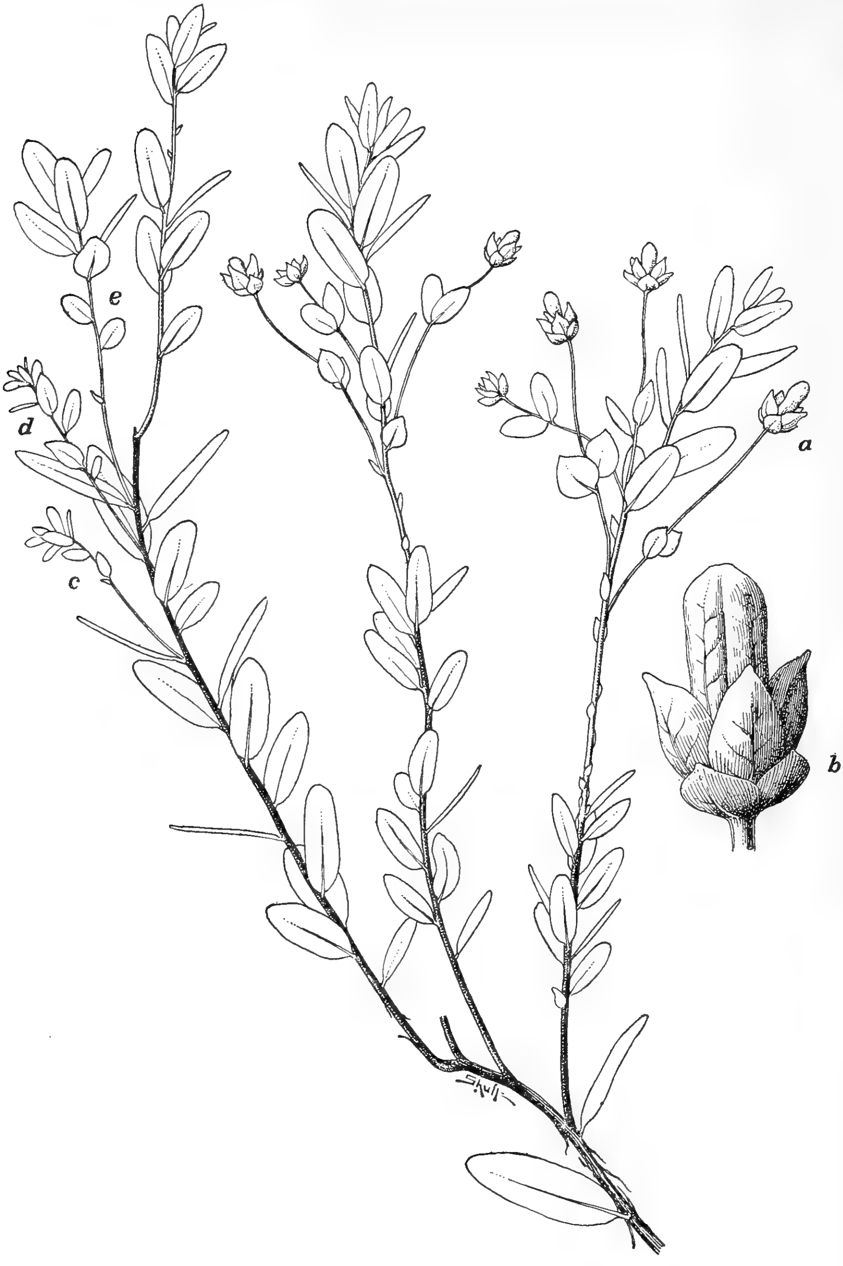
> The dryness of the season seems to have reduced the amount of "false blossom" this year, and from the data gathered in the Mather region, it has become more evident than ever that this so-called "false blossom" is due to conditions of culture rather than any disease affecting the plant.

In all the localities in Wisconsin in which the writer has observed this malformation, there has been a deep, coarse, peat soil, supplied with an excessive amount of water during the greater part of the growing season. Of course these peat bottoms contain vast quantities of nitrogenous matter, but not in such form as to be available to ordinary farm crops. The cranberry, however, is regarded by physiologists as obtaining its nutriment chiefly by means of the endophytic mycorrhiza of its roots and may be able to secure an abundance of

A NORMAL FRUITING BRANCH OF A CRANBERRY VINE AND A SHOOT WITH MALFORMED FLOWERS.

FIG. 1.—A fruiting branch of a cranberry vine with normal flowers in different stages of development: *a*, An unopened bud; *b*, an open flower; *c*, the young fruit just after the blossom has fallen; *d*, young fruit.

FIG. 2.—A cranberry shoot, showing the simplest forms of malformation of flowers: *a*, A flower with the calyx lobes somewhat broader than normal and the petals much shortened and broadened; *b*, a flower with the sepals broadened and divided to the base; the petals are also short, broad and virescent, approaching a foliaceous condition; the stamens are somewhat shortened and abnormal, and the ovary abnormal, elongated into a conical form, and infertile; *c*, a condition very similar to that shown in *b*. These illustrations were made from plants collected near Grand Rapids, Wis., on June 29, 1907.



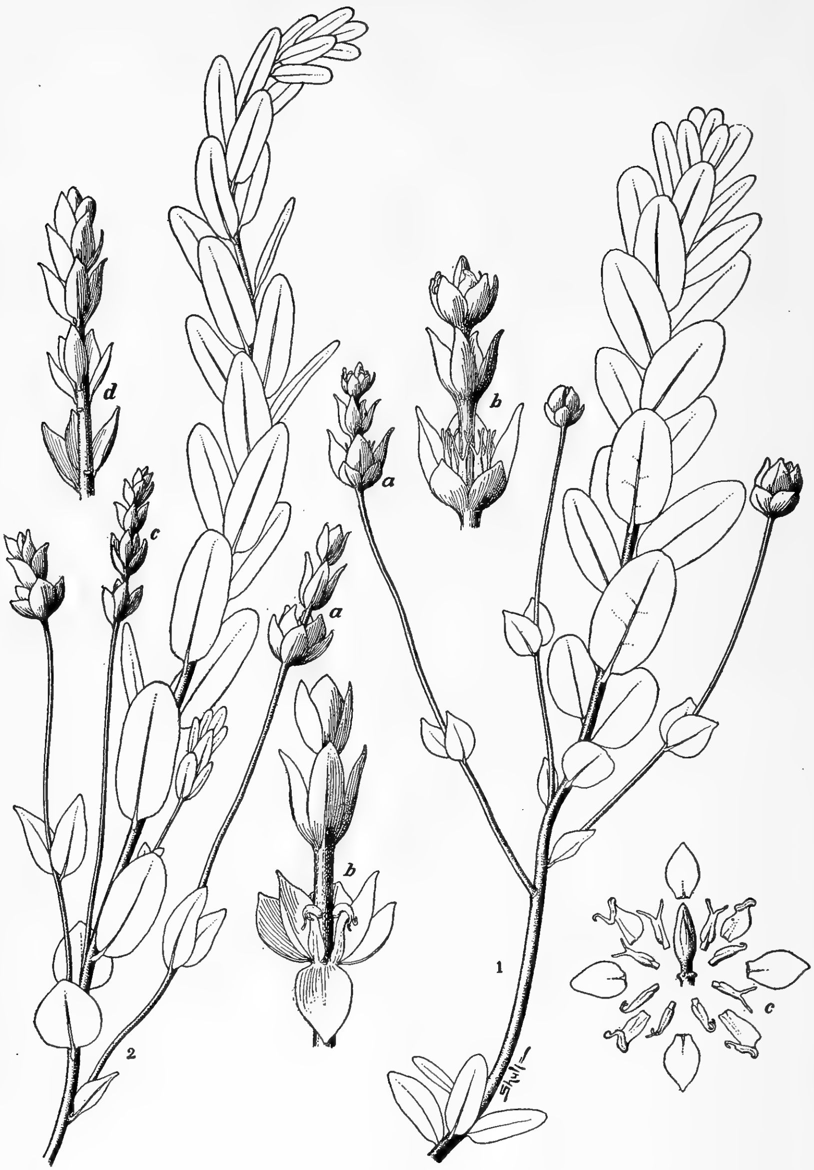
A PORTION OF AN UPRIGHT BRANCH OF A CRANBERRY VINE IN WHICH THE TERMINAL BUD, WHICH NORMALLY PRODUCES A FLOWERING AND FRUITING SHOOT, FAILED TO DEVELOP. IN ITS STEAD THREE SHOOTS AROSE FROM NORMALLY DORMANT AXILLARY BUDS.

a, An abnormal flower in which the sepals are short, broad, virescent, and divided at the base; petals short, broad, and mostly virescent; stamens present, but shortened and somewhat abnormal in form. The ovary is prolonged into a columnar form, is virescent, and shows four depressed lines representing points of origin of the division walls of the ovary, which easily ruptures along these lines; *b*, an enlarged figure of the same flower; *c*, *d*, and *e*, flower pedicels in which the floral organs have all been transformed into small foliaceous structures, *e* representing the most advanced condition of this transformation, in which, instead of a flower, an almost normal foliaceous shoot is produced.

FLOWERING SHOOTS OF CRANBERRY VINES, SHOWING VARIOUS STAGES OF PHYLLODY.

FIG. 1.—A flowering shoot with three different stages of phyllody: *a*, The most pronounced condition, in which sepals and petals are abnormal in form and virescent. Instead of an ovary, the axis is elongated, bearing a whorl of four small, green, leaflike bodies, and this is followed by another similar whorl, within which are two other partially developed organs of the same kind; *b*, an enlarged figure of the same, and, *c*, a section of the basal whorl, representing sepals and petals, showing the condition of the anthers, which were present in a somewhat abnormal form in almost all cases except in the condition represented in Plate IV, *c*, and also in Plate II, *c*, *d*, and *e*.

FIG. 2.—A flowering shoot in which two of the flowers are still more greatly transformed: *a*, In this case the axis of the flower, after being prolonged and bearing a whorl of small, green, leaflike bodies, is continued, producing a series of small leaves, the lower more or less whorled, but those above tending toward an alternate arrangement similar to that of a normal shoot; *b*, a form in which the elongated axis has all the small leaflike bodies more or less alternately arranged. In all these cases, abnormal stamens were present in their normal position.



TRANSFORMATIONS OF FLOWERS OF THE CRANBERRY IN VARIOUS STAGES OF PHYLLODY.

FIG. 1.—Modifications of the transformation of flowers: *a*, The flower with green, abnormally shaped sepals and petals; the axis prolonged, bearing two whorls of small, green, leaflike bodies, the upper whorl with eight abnormal stamens, the lower also with stamens; *b*, an enlarged view of *a*; *c*, the upper whorl of *b*, dissected, showing the abnormal floral organs. Within the outer whorl of four short, broad bodies, were four much malformed organs, showing the condition intermediate between an aborted petal and a stamen. Within this whorl were eight abnormal stamens and at the center a partially opened bud, with two small, partially developed leaflike organs.

FIG. 2.—A shoot in which the flowers are still further transformed: *a*, All the parts of the flower except the stamens are green and more or less leaflike; *b*, an enlarged view of *a*, showing the condition of the stamens; *c*, a stage in which the parts, instead of being arranged in whorls, are more or less alternate or spiral; *d*, an enlarged view of *c*. There is no sign of stamens present in any of these groups of small, green, leaflike bodies in *c*, the stamens being apparently the last organ to disappear in the metamorphosis of the flower.

nitrogen from these soils, as it usually shows great luxuriance of vegetative growth where the water supply is abundant. Mr. Malde (7) corroborates this view and states that the development of the disease appears also to be favored by extreme drought or lack of water.

CONTROL.

It appears from experiments conducted by Mr. Malde at the Wisconsin Cranberry Station and reported to the writer that malformed plants when transplanted and kept under more favorable conditions tend to return to the normal form. The writer has been told by a grower on the Pacific coast that plants from Wisconsin showing phyllody have entirely recovered from the disease when grown on that coast. The cases in Massachusetts previously mentioned indicate, however, that under rather favorable conditions of cultivation in the Eastern States the disease persists for a long time in affected vines.

Owing to the obscure nature of this disease and the difficulties involved in carrying out satisfactory experiments to determine definitely its cause and nature, but little has yet been accomplished in this direction. On the basis of the present theories of the cause of the trouble, recommendations have been directed chiefly toward correcting and making as nearly optimum as possible the soil and nutritive conditions under which the plants are grown, as indicated in the writer's papers presented at the Wisconsin State Cranberry Growers' Association (9 and 11). This involves sanitary measures, such as clean cultivation, thorough drainage, pruning, and fertilization where needed. In cases where half or more of the plants in an area are affected, it is best to mow off the vines, properly drain the bog, and apply ground rock phosphate, which Mr. Malde believes beneficial. In bad cases it will probably be best to scalp the bog and replant with healthy vines (11).

Experiments have been undertaken in Massachusetts to determine definitely whether the transmission of the disease to normal plants when grown in contact with diseased plants is possible.

Plants from diseased bogs should be carefully avoided in making new plantings. Even though under optimum conditions of growth the plants may outgrow the trouble in time, they will not produce a profitable crop as soon as healthy vines.

SUMMARY.

The disease known locally as false blossom in Wisconsin is a true case of phyllody.

The floral organs show all degrees of transformation from normal flowers to those in which the parts are all changed to green leaflike bodies and the axis prolonged into a shoot.

The disease appears to have originated in Wisconsin, but has become established in Massachusetts, New Jersey, Oregon, and Washington by transplanting diseased vines.

The cause is not known. No evidence has yet been obtained to indicate that it is produced by insects or fungi.

It is suggested that the disease may be due to unbalanced nutritive conditions.

The disease is perpetuated from year to year in plants reproduced vegetatively from diseased plants, not only in bogs where the trouble originated, but also under somewhat more favorable conditions of cultivation in localities in which the disease was unknown previously. Observations made by Mr. Malde in Wisconsin and by a grower in Oregon seem to indicate that the offshoots from plants affected with false blossom tend to recover and become normal when transplanted and grown under optimum soil and moisture conditions.

To overcome the disease, optimum conditions for growth should be provided, including good drainage, clean culture, and pruning.

Where diseased plants are numerous, the bog should be scalped and replanted with healthy vines.

To prevent the further spread of the disease only vines known to be absolutely free from it should be planted.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 445

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ February 10, 1917

THE NAVEL ORANGE OF BAHIA; WITH NOTES ON SOME LITTLE-KNOWN BRAZILIAN FRUITS.

By P. H. Dorsett, A. D. Shamel, and Wilson Popenoe, *Agricultural Explorers, Office of Foreign Seed and Plant Introduction.*

CONTENTS.

	Page.
Introduction	1
Origin and history of the navel orange of Bahia	1
Introduction of the Washington Navel orange of Bahia into the United States	4
Culture of the navel orange in Bahia	7
Citrus fruits of Bahia other than the navel orange	15
Citrus fruits of the region around Rio de Janeiro	16
Miscellaneous fruits grown at Bahia	17
Some interesting fruits of Rio de Janeiro and vicinity	25
Fruits of the highlands and semiarid regions of Minas Geraes and Bahia	31

INTRODUCTION.

Since the introduction of the Washington Navel orange from Brazil 45 years ago, its culture in California has been continually extended, until to-day the industry produces an annual income of something like 30 millions of dollars. Yet, in spite of the importance of this fruit, little has been known in the United States of its history in its native home, Brazil, or of the methods and practices of Brazilian orange growers.

ORIGIN AND HISTORY OF THE NAVEL ORANGE OF BAHIA.

Unfortunately, the origin of this remarkable fruit is somewhat obscure, and the only available accounts are those which have been handed down from father to son and are still preserved among a few of the Brazilian orchardists. It is the general belief among the latter that the navel orange came into existence at Bahia in the early part of the nineteenth century. It is believed to have been first propagated by a Portuguese who lived at Cabulla, a suburb of Bahia City. This section is at the present day the most important orange-growing district of Bahia (Pl. I), though most of its commercial plantations do not date back more than 40 or 45 years. The name of the originator does not appear to be known at the present day, or the exact location of the property on which the variety originated. Only the most fragmentary accounts are given by the orange growers, who should and probably do know more about the subject than most others. The most complete and probably the most accurate statement is that furnished by the Rev. W. A. Waddell, a Presbyterian missionary, who has lived for years in the vicinity of Bahia and has been much interested in this subject, as follows:

> Twenty years ago an old man, a very intelligent cabinetmaker, told me that in his youth, before the independence of Brazil, the laranja de umbigo (navel orange) was found only in some groves in Cabulla. He, as a boy soldier, in company with his comrades, "chupou muitas" (ate many) during the siege of Bahia, being stationed in a grove that contained some trees. Most of his comrades had never seen them before, but he had seen them sold by the slaves of a Portuguese. He had heard that a "mandinga" woman charmed a seed and made the first tree yield "umbigoed" fruit. This was information gathered when he was young, say, 1816 or 1818. I came to the conclusion that the seedling tree originated in Cabulla in 1810–1820, or perhaps even earlier, and was first propagated by a Portuguese grower, and that in 1822, the year of Brazilian independence, there was quite a lot of trees. Of course, the production of any odd-shaped fruit would be explained by fetichism among the lower classes.

It will be noted that Dr. Waddell speaks of the "seedling tree" which originated in Cabulla. All the evidence, however, indicates that the variety originated as a sport, or mutation, upon a Selecta orange tree, laranja selecta, as it is known in Brazil. The Selecta is almost identical with the navel orange in many characters and frequently shows a marked tendency to produce navel fruits, even though it is normally without any vestige of a navel. The Bahians themselves recognize the similarity between these two varieties and call the navel orange "Selecta de umbigo," or navel Selecta. This name may, in fact, have been given to the first navel tree to indicate its origin.

The Selecta orange, while rarely seen at Bahia, is still cultivated commercially in the vicinity of Rio de Janeiro, especially at Sao Gonçalo, a suburb of Nictheroy. In one of the groves of this section, that of Joao Elias Esteres, the presence of occasional fruits with well-defined navels was observed on trees which normally produced typical Selecta fruits. The navels in these fruits were in some cases as large and well developed as in the typical navel orange, although they did not protrude through an opening in the apical end of the fruit as commonly as in the latter variety.

The typical Selecta orange (Pl. II) is slightly oblate in form and contains 15 to 20 seeds. In bud-sport fruits with navels (Pl. III), the form tends to become more nearly that of the navel orange, i. e., spherical, and the number of seeds was reduced to an average of nine in the specimens examined.

When all the evidence is considered, there is scarcely any room left for doubt concerning the origin of the navel orange of Bahia as a sport from the Selecta variety. Other accounts obtained at Bahia substantiate the belief of Dr. Waddell that the variety originated in the Cabulla district during the first or second decades of the nineteenth century.

The origin of the Selecta orange is even more obscure than that of the Bahia navel. It has been known in Brazil since a remote date, and in all probability was brought there by the Portuguese from the Iberian Peninsula, though it might have come through one of the Portuguese settlements in the Orient. An article which appeared in "The Garden" and is quoted in the report of the United States Department of Agriculture for 1877 mentions it as occurring in the Azores, with the note that it is "large, of first-rate flavor, little acidity, and of deep yellow color. It has scarcely any pips and does not ripen until April, which gives it a higher value." In Rio de Janeiro it is preferred by many to the navel orange; in fact, it is classed by some as the best orange in Brazil. Its fine quality at Rio de Janeiro may be due in some measure, however, to the effect of climate or soil.

The extension of the navel-orange industry in Bahia, which has resulted in the present large groves of Cabulla, Matatu, and other districts near the city of Bahia, has taken place since 1860 or 1870, according to the statements of the oldest orchardists. This is about the time of the introduction of the variety into the United States. Previous to that time there were only a few small groves in the Cabulla district. A census taken in 1913 by Dr. V. A. Argollo Ferrão showed that there were in the territory immediately adjacent to the city of Bahia about 67,000 trees, and about 6,000 more in small plantations in the interior of the State, notably at Matto de Sao Joao, Santo Antonio de Jesus, Amargosa, and Bom Fim, making a total of 73,000 trees. The principal orange districts within the municipality, as shown upon the map (p. 8), are as follows: Cabulla, containing about 30,000 trees; Saboeiro, with 12,000 trees; Cruz do Cosme, 7,000 trees; Matatu, 8,500 trees; Brotas, 6,000 trees; Sao Gonçalo, 2,000 trees; and Victoria (including Barra, Graça, and Rio Vermelho), 1,500 trees. As there are usually about 100 trees to the acre, the total acreage in oranges within the State is approximately 730. About one-third of the total number of trees have been planted less than three years; one-third are from 3 to 6 years of age, and the remaining third, 6 to 40 years of age.

At the present time nearly the entire crop is consumed locally. While small shipments are made to Rio de Janeiro and the steamers which call at Bahia usually take on oranges for use on board, an established trade has not been developed. Yet new orchards are being planted every year and the growers seem to be awakening to the possibility of developing a vastly larger and more profitable industry, with the hope of building up an export trade which will include not only Europe but eventually the United States as well. Because of superior transportation facilities, the European markets are likely to be entered first. In the past the high cost of transportation, crude methods of packing and handling, and other factors have prohibited exportation to distant countries. With fast steamers and the introduction of modern methods of packing and shipping there seems no reason why Bahia should not enter the export field.

The cultivation of this variety in Brazil is not limited to the State of Bahia. It has been planted in other parts of the Republic, but in nearly all cases less extensively than at Bahia itself. Commercial orchards are said to exist in the States of Sao Paulo and Rio Grande do Sul. In orchards around Rio de Janeiro the variety is very rarely grown.

INTRODUCTION OF THE WASHINGTON NAVEL ORANGE OF BAHIA INTO THE UNITED STATES.

The United States owes the successful introduction of the navel orange to the late William Saunders, Horticulturist, Landscape Gardener, and Superintendent of Gardens and Grounds of the United States Department of Agriculture. It is not certain, however, that the trees which were introduced by Mr. Saunders were the first which had been brought to the United States, though they were the first to come into successful bearing. The late Thomas Hogg, of New York, in an account published in 1888, stated that about 1838 a wealthy Scotch planter in Brazil determined to manumit his slaves and remove with them to the United States. He settled on an island in middle or southern Florida and then returned to Brazil and secured a collection of plants for introduction, which he consigned to Mr. Hogg, who at that time conducted a nursery at the corner of Broadway and Twenty-third Street, New York. Among these plants were several navel-orange trees. After the plants had been held in a greenhouse for a year, in order to allow them to recover from the effects of the long sea voyage which they had undergone, they were forwarded to the owner in Florida. During the Seminole War the owner was charged with giving aid and comfort to the enemy, and the entire collection of plants was destroyed by the United States troops. The owner then moved to Haiti.

While it can not be positively stated that these trees were of the same variety as that subsequently introduced by the United States Department of Agriculture, it seems probable that this was the case. None of the trees survived long enough to come into fruit, however, and no trace of them now exists.

In a private notebook of Mr. Saunders, now in the possession of his daughter, Miss Belle C. Saunders, is to be found the following entry:

DECEMBER 20, 1898.

I propose to note from time to time some reminiscences of persons and things. Also make mention of such items as I desire to establish as worthy of record in my practice, items that have been more or less of value in horticultural and kindred pursuits.

WILLIAM SAUNDERS.

This note indicates that Mr. Saunders wrote the following unpublished account (appearing in that notebook) of the successful introduction of the navel orange some time between December 20, 1898, and the date of his death, September 11, 1900:

Some time in 1869 the then commissioner of agriculture, Horace Capron, brought to my office and read to me a letter which he had just received from a correspondent at Bahia, Brazil. Among other matters, special mention was made of a fine seedless orange of large size and fine flavor. Thinking that it might be of value in this country, I noted the address of the writer and sent a letter asking to be the recipient of a few plants of this orange. This request brought, in course of time, a small box of orange twigs, utterly dry and useless. I immediately sent a letter requesting that some one be employed to graft a few trees on young stocks and that all expenses would be paid by the department. Ultimately a box arrived containing 12 newly budded trees, and, being packed as I had suggested, were found to be in fairly good condition. I believe that two of them failed to grow. No expenses were charged, so I presume that the correspondent sent them as a gift. All that I ever knew about the donor was that she was a lady, and that the correspondence, so far as she was concerned, was not official.

I had a supply of young orange stocks on hand, and as fast as I could secure buds they were inserted on these stocks. The first two young plants that were sent out were sent to a Mrs. Tibbetts, Riverside, Cal. That lady called here and was anxious to get some of these plants for her place, and I sent two of them by mail. They prospered with her, and when they fruited attention was directed to their size and fine appearance, and when ripe their excellence was acknowledged, and the fruit was called Riverside Navel, thus ignoring the label attached to the plants, which was Bahia, a very distinctive name, which should have been retained. Afterwards other Californians, not wishing Riverside to be boomed with the name, changed it to Washington Navel, all of which was uncalled for, but this department could not alter it, and it was considered best to adopt the name and so avoid further confusion.

We budded many hundred from time to time and sent them to Florida, where it has never become very popular, owing to its not bearing plentifully. I have seen trees 15 feet in height, fine trees, at Rockledge with not over a couple of dozen fruits on them. Why it fruits better in California than it does in Florida is not known. In the orange house of the department it has never fruited heavily, but is most profuse in flowers. It was thought that the original trees were not all of one kind and that those sent to Florida were different varieties. This was a mistake, as all were fruited here and all were alike. * * * Many thousands of acres have been planted and upward of 2,000 carloads of fruit have been transported to the East in one year. It has also been received with favor in the English market, some sent to London having brought good prices. It has proved to be, perhaps, the most valuable introduction ever made by the Department of Agriculture in the way of fruits.

Some years ago Rev. W. A. Waddell, already referred to in connection with the origin of the navel orange, was in Riverside, Cal., and saw the two original trees which were sent by Mr. Saunders to Mrs. Tibbetts. Becoming interested in their history, he made inquiries of some of his associates when he returned to Bahia, and was told by the Rev. F. I. C. Schneider, the first Presbyterian missionary to Bahia, that he was the one who had secured and packed the trees which were sent to the United States in 1870. Mr. Schneider, who died about three years ago, told of an earlier shipment that had been sent to the United States, but word was sent back that the trees had all perished during the voyage. Some one requested Mr. Schneider to prepare a shipment as carefully as possible, and he did so.

Several old friends of Mr. Schneider were interviewed in Bahia, to see if any account of this shipment could be obtained. One of them, Carlotta da Boa Morte, whose mother was a servant in the Schneider household, clearly recalled the incident. She stated that while she was yet a girl and was living with her mother at the Schneider home Mr. Schneider one day took the family for a picnic to Engenho Velho, a large farm in the suburbs of Bahia, owned by Sr. Teixeira. They spent the day there, and before they returned to town Sr. Teixeira brought in a number of navel-orange trees, and also a few of the lima doce, or sweet lime, which he packed in boxes and sent to Mr. Schneider's house in the city. Here, after long discussion of the best method of packing them to withstand the trying voyage which was before them, they were placed in a wooden crate and dispatched to the United States.

The fazenda (farm) of Engenho Velho, where the trees were obtained, has been divided in recent years, but a portion of it still remains in the possession of Sr. Teixeira's son. A number of old orange trees, uncared for and in bad condition, are still growing on the property. Some of these may have been the parents of the young plants which were sent to North America. The younger Teixeira states that the orchard was planted originally with budded trees from the grove of Sr. Barro Reis, in Cabulla, but he knows nothing about the young trees supplied to Mr. Schneider.

CULTURE OF THE NAVEL ORANGE IN BAHIA.

CLIMATE.

The climate of Bahia is warm and humid, with more or less well-defined wet and dry seasons, the wet season beginning in February or March and lasting until June or July, when the dry season normally commences and continues until the following January. The rainfall is not, however, limited to the wet season, although it is much heavier at that time than during the remainder of the year. The size of the orange crop and the quality of the fruit are said by the orchardists to be affected materially by the amount of rainfall, the largest crops and the best fruit being produced when the rains are unusually heavy.

The annual precipitation for the last nine years has varied from 40 to 73.35 inches, both these extremes being unusual; ordinarily there is a rainfall of 55 to 65 inches. The temperature of this region is more or less uniform throughout the year and comparatively constant during the entire 24 hours. Frost is unheard of, the lowest recorded temperature during the last nine years being 63° F. The highest temperature for the same period is 101° and the mean temperature 76.4° F. From January to June the mean temperature usually ranges from 75° to 80° F.; from June to September there is a slight drop, the average being 72° to 75° F. October, November, and December are slightly warmer, varying from 77° to 80° F. These figures are based upon data obtained at the State meteorological station, near the city of Bahia (Table I).

Table I.—*Temperature and precipitation at Bahia, Brazil, 1904 to 1912, inclusive.*

Year.	Temperature (° F.).			Total precipitation.	Year.	Temperature (° F.).			Total precipitation.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
				Inches.					*Inches.*
1904	101	64	76	59.1	1909	93	66	76	59.4
1905	91	64	76	67.5	1910	92	66	76	63.5
1906	95	63	76	62.25	1911	92	67	77	73.35
1907	92	63	76	40.0	1912	95	67	77	71.9
1908	92	64	78	56.5					

SITUATION OF THE ORANGE ORCHARDS AND THE SOIL CONDITIONS.

The land in the immediate vicinity of Bahia is, for the most part, a series of low, rambling hills, not over 100 or 200 feet in height, with intervening level valleys where the soil is frequently wet and best suited to the cultivation of such plants as Angola grass (*Panicum barbinode* Trin.), an important forage crop both for horses and for cattle. Practically all of the orange groves are located on the hilltops (fig. 1 and Pl. IV), frequently extending down the hillsides to the borders of the valleys. As terracing is not practiced, the hillside soil is sometimes bady eroded.

The surface soil on the hilltops is usually a rather coarse, sandy loam a foot or more in depth, underlain by the heavy, yellowish red clay which is characteristic of the region. On the hillsides, which are subject to erosion by the rains, the surface loam is lacking. The clay

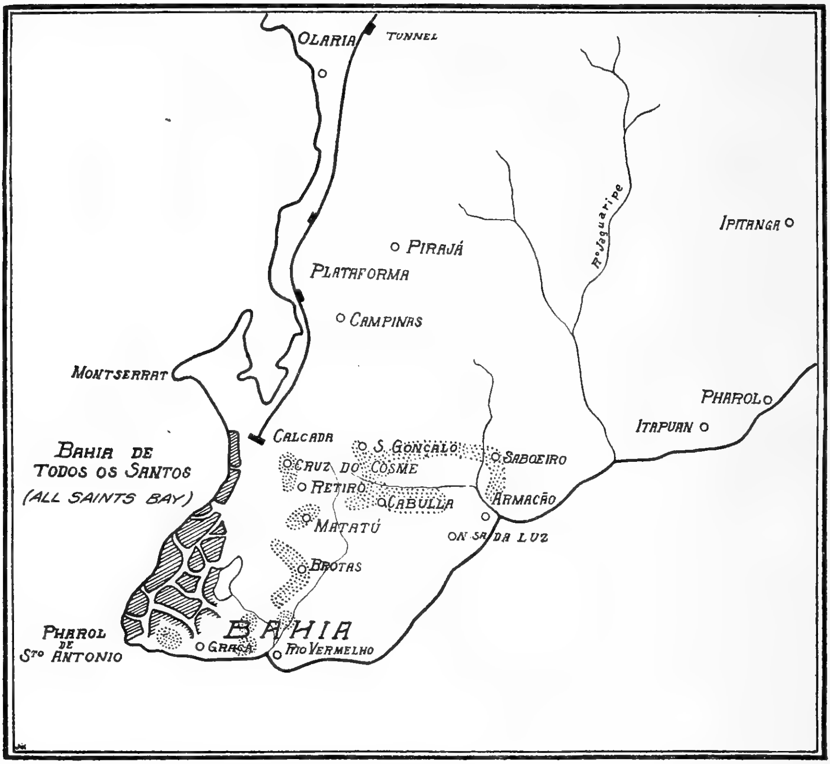


FIG. 1.—Sketch map of the vicinity of Bahia, Brazil, the dotted areas showing the principal districts where navel oranges are grown.

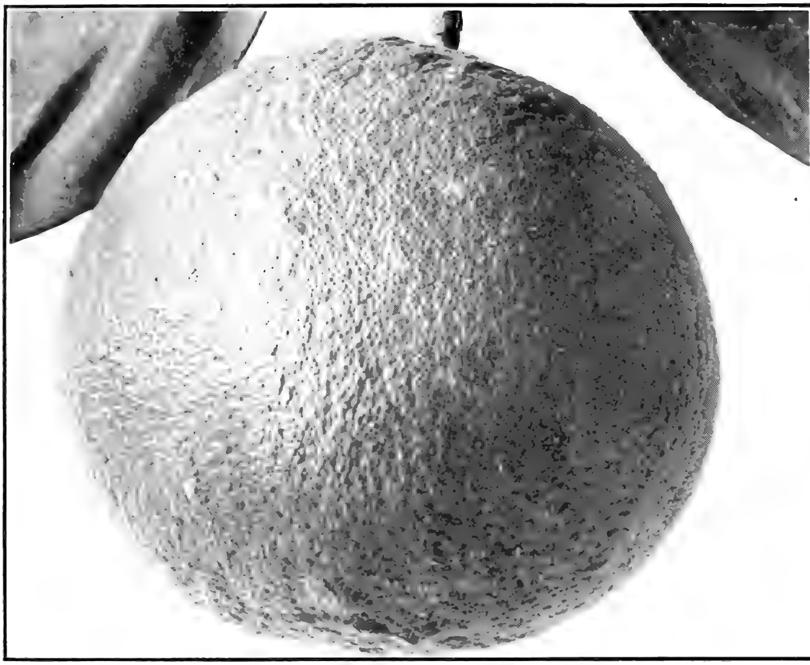
soil, though occasionally shallow, frequently extends to a depth of 30 feet or more, as shown by numerous railway and road cuts in the region. It commonly rests on granite.

Before clearing, the land is covered with shrubby vegetation, nicurí palms (*Cocos coronata* Mart.), mangabeiras (*Hancornia speciosa* Gomez), and sometimes virgin forest. The presence of the mangabeira is taken as an indication that the land is suitable for orange culture. The municipality of Bahia includes about 50,000 acres of arable land, of which it is claimed about 35,000 acres are typical citrus soil.

P15355FS

A NAVEL-ORANGE ORCHARD IN BAHIA, BRAZIL.

A portion of the orange grove of Col. Lago, at Cabulla, near the city of Bahia, one of the largest groves in Bahia State, containing about 9,000 trees. Those with dark-colored foliage in the central rows are tangerines. Hillside land is nearly always selected for orchards in this region. It is cleaned of weeds but not cultivated deeply before or after planting. Photographed December 12, 1913.



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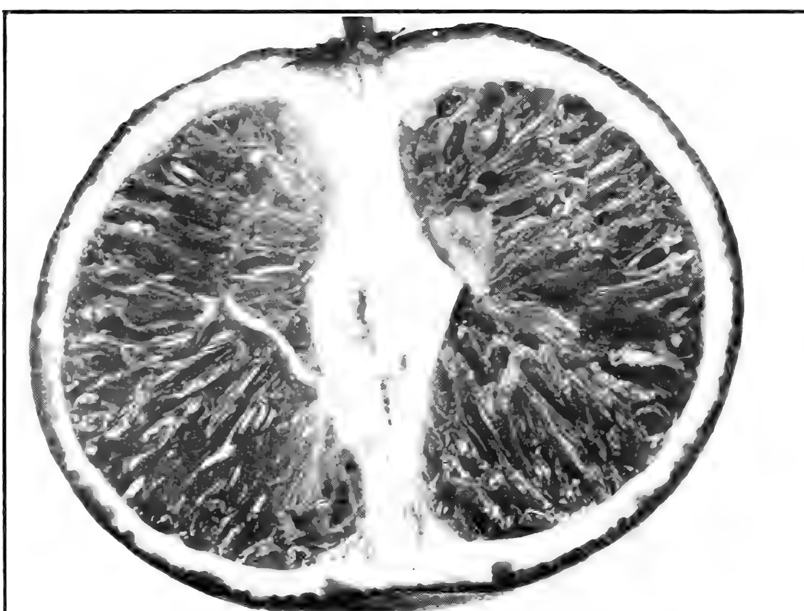
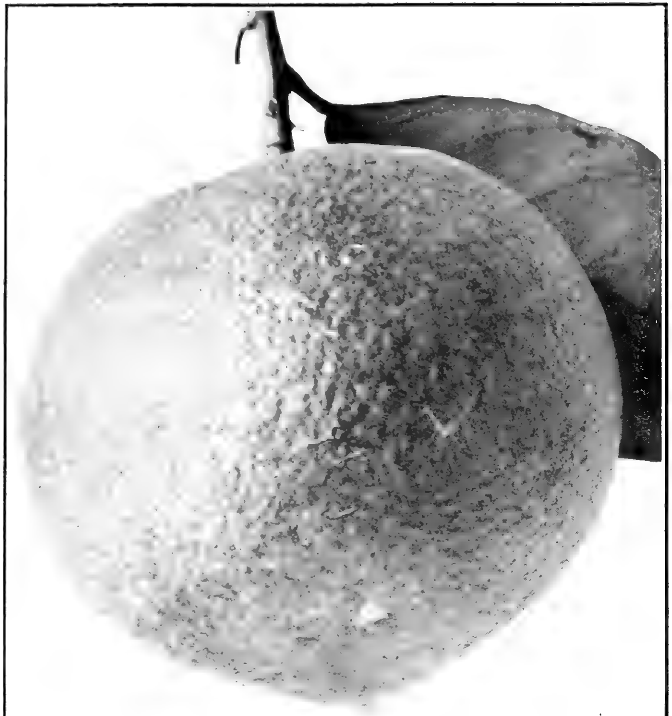


P16041FS

A TYPICAL FRUIT OF THE SELECTA ORANGE AND A LONGITUDINAL SECTION OF THE SAME.

While normally of the shape shown and devoid of any vestige of a navel, the variety occasionally produces fruits with internal or even externally prominent navels, resembling in every way those of the Bahia or true navel orange. This and other evidence indicates that the Bahia navel originated as a sport or mutation from the Selecta orange, a variety which has been cultivated in Brazil since a remote date and is grown commercially near Rio de Janeiro. Photographed at Rio de Janeiro, Brazil, March 20 and 23, 1914. (Natural size.)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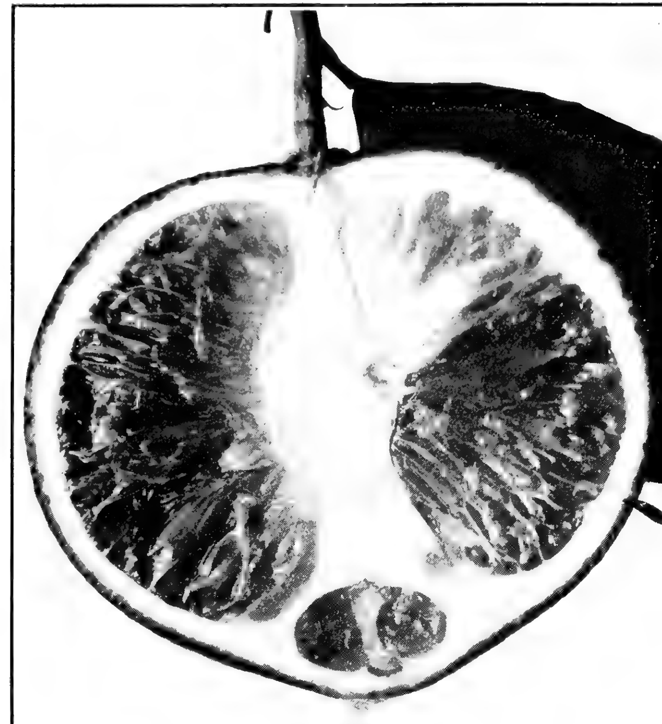
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A BUD-SPORT FRUIT AND A LONGITUDINAL SECTION OF THE SAME FROM A SELECTA ORANGE TREE IN THE GROVE OF SR. JOÃO ELIAS ESTERES, NICTHEROY, BRAZIL.

Most of the fruits on the trees in this grove were normal in type, resembling those shown in Plate II. A few were found, however, which departed from the normal and were swollen at the apex, indicating the presence of an internal navel, like that shown above. In a few other bud-sport fruits found upon Selecta trees the navels were as prominent externally as in the average Bahia navel orange. Photographed at Rio de Janeiro, Brazil, March 20, 1914. (Natural size.)

P14495FS

A NAVEL-ORANGE ORCHARD ON A HILLSIDE NEAR BAHIA, BRAZIL.

Most of the orange orchards in the vicinity of Bahia are planted on hillsides, the soil being a heavy reddish clay. This illustration shows a portion of the Barretto orchard, one of the principal ones of the Cabulla district. In the foreground is a field of Angola grass (*Panicum barbinode*), which is extensively grown as a green forage crop. Photographed December 13, 1913.

PROPAGATION AND STOCKS USED FOR THE NAVEL ORANGE.

Shield budding, essentially the same as practiced in the United States but differing in a few minor details, is the method used for propagating the navel orange in Bahia. Seedlings of laranja da terra (*Citrus aurantium* L.), the bitter or sour orange, are practically always employed as stock plants. The chief reason for the almost exclusive use of this stock seems to lie in the fact that it is more easily budded than others. Laranja da china (*Citrus sinensis* (L.) Osb.), which is sometimes used, is objected to in Brazil because of its thorniness, and also because it does not heal well around the bud and is apt to die back when it is cut off after the bud has started into growth. Very little is known of the comparative effect of these two stocks on the scion, but some of the orchardists in Rio de Janeiro, where both these stocks are used, hold that laranja da china produces a longer lived tree than laranja da terra.

Seeds of laranja da terra are sown in beds or rows, preferably on high, well-drained, sandy land. When the seedlings have attained a height of about 6 inches they are either transplanted to nursery rows about 3 feet apart, setting the plants about 12 inches apart in the row, or they are transferred to the place the budded trees are to occupy permanently in the new orchard and later budded in situ. The orchardists give as a reason for this latter practice that it produces hardier trees and that the trees come into bearing sooner than those transplanted from the nursery after budding.

When the seedlings are 1 to 2 years old they are budded, no care being used in the selection of bud sticks, as a rule, other than to cut thrifty water sprouts from large and vigorous trees. Budding is usually done in the dry season; buds cut in the shape of a shield three-fourths of an inch to an inch and a half in length are inserted in the stocks 15 to 20 inches above the ground. The bud sticks are sometimes an inch or more in diameter, the small bud wood generally used in the United States not being considered desirable by Bahia propagators.

Budding is always done when there is an abundance of sap in both stock and scion and the bark slips readily. If either is found to be dry and the bark does not slip readily, the operation is postponed until a more favorable time.

The incision in the stock is made in the form of an inverted **T**. The bud, after insertion, is tied firmly in place with a portion of a leaflet of the nicurí palm (*Cocos coronata* Mart.), made soft and pliable by scalding. This palm is common in all the orange-growing districts of Bahia. Fifteen days after insertion the wrap is removed, and at the end of another 15 days, if the bud has started into growth, the stock is cut off about 2 inches above it.

At the end of six months to a year, if grown in the nursery, the young trees are ready for transplanting. The tender growth is removed and the plant dug with a ball of soil around the roots. If they are to be kept any length of time before planting in permanent locations or are to be offered for sale in the markets, as is often the case, the trees are placed in small baskets, about 6 to 8 inches in diameter and 8 to 12 inches in depth, made from splints from the woody leafstalks of the dendé palm (*Elaeis guineensis* Jacq.). These baskets take the place of the clay flower pot and are widely used.

PLANTING AND CULTURAL PRACTICES.

The cost of uncleared lands suitable for orange culture near the city varies from $10 to $100 per acre, and farther away, from $3 to $15 per acre. The expense of clearing is frequently more than met by converting the natural growth of timber into charcoal, which can always be sold at a remunerative figure. Immediately after clearing, the orange trees may be set and mandioca (*Manihot esculenta* Crantz) planted between the rows, or the ground may be cultivated to mandioca for a year before the oranges are set out. Mandioca matures in one year. The cost of planting, cultivating, and harvesting the crop is about $20 per acre and its value from $30 to $40 per acre, leaving a sufficient profit as a rule to cover the cost of planting and caring for the orange trees during the first few years of growth, after which the cultivation of mandioca in the orchard is discontinued.

It is customary to plant from 80 to 100 trees to the acre, though on rich soils this may be increased to 120. The market price of budded trees varies from 65 cents to $1 each, according to size. In planting, the crown of the roots is barely covered with soil. In dry seasons it is sometimes necessary to water the young trees by hand for a few weeks, but beyond this little or no irrigation is practiced.

In most groves the only cultivation consists in clearing the land of weeds two or three times a year with a heavy hoe. Labor for this purpose costs 30 to 60 cents a day. Sometimes the work is let out on contract at the rate of $3.30 per acre for each cleaning. Hoeing is usually done during the dry season, when conditions are most favorable for killing the weeds.

The most healthy, vigorous, and productive orchard observed in Bahia was planted to Angola grass (*Panicum barbinode* Trin.; Pl. IV), which prevents soil erosion and is at the same time an important source of income as a green forage. Manure is frequently applied to stimulate the growth of the grass, the oranges, no doubt, sharing in the benefits of this practice. In most of the small groves little or no manure is applied directly to the trees; in some of the larger ones, however, the practice of applying manure or other fertilizers has become common in recent years. Several groves in which the trees were formerly starved, unhealthy, and unproductive are said to have been brought back to a state of health and fruitfulness by the use of manure.

Dairying in connection with orange culture is an interesting feature of the Bahia orange industry. The milk is sold in the city at a very profitable price, usually 25 cents a quart at retail and 15 cents at wholesale. The manure is used on the orchards and in every case is said to have had a marked effect in increasing the production and health of the trees.

As a rule, little pruning is practiced. When the trees become old and seriously weakened by the ravages of gum disease they are often renewed by allowing the suckers which start up from the trunk above the union of the stock and scion to form a new top; in fact, it might be called a new tree. The old trunks are either allowed to rot off or are cut away. Having a large and established root system, the suckers make rapid growth and often begin to bear fruit within two or three years.

The orchards usually come into bearing within two or three years after planting. The oldest known trees in Bahia were planted over 40 years ago and are still producing good crops of fruit.

ENEMIES OF THE ORANGE TREE IN BRAZIL.

In the older orchards many of the trees are affected by gum disease, which seriously impairs their health and eventually kills them or results in their having to be renewed by the production of suckers from below the affected region on the trunk.

Chlorosis, or mottle-leaf, exists in many of the orchards, but the growers take no cognizance of its existence as a disease. They consider it a constitutional weakness of the tree due to a lack of proper nourishment.

A parasitic vinelike shrub known as herva de passarinho, a species of Phoradendron, is frequently found on the trees and has to be removed. If allowed to remain, it will in time smother the tree. Several epiphytic plants of the order Bromeliaceæ are also occasionally found on orange trees, but do not, it is believed, cause any appreciable injury and are easily removed. The trunks of the trees, especially in the older orchards, are covered with lichens, algæ, and other low forms of plant life, none of which apparently does any very serious harm.

Scale insects of several species are prevalent, but seem to be held in check by some natural agency and do not as a general thing appear to produce serious results. Practically the only insect which is an actual menace to the industry and against which combative measures are taken is the saúva or saúba ant (*Atta* sp.).

These ants are black and about half an inch in length. The head in proportion to the body is large. The species is probably closely related to the leaf-cutting ant of Texas and Cuba (*Atta* sp.). While they cut the leaves of practically any plant, they appear to be particularly fond of orange leaves, and it is not infrequent in Brazil to see a good-sized orange tree nearly defoliated in a single night. The leaf-cutting ants are practically agricultural ants. The fragments of the leaves cut from the trees are carried into a chamber in their nests. Here they decay and form the basis for their so-called "mushroom garden." The fungi that are cultivated upon these small bits of decaying leaves supply the food of the entire colony. It is reported, and doubtless is true, that these gardening ants exercise every precaution to prevent their mushroom beds from becoming contaminated by other species of fungi. The Brazilian farmer combats this pest by forcing hot fumes of sulphur into the runways.

In view of the fact that no serious effort is made to combat insect or fungous enemies other than the saúva ant, the comparatively small amount of injury which such enemies appear to do is remarkable.

THE ORANGE CROP OF BAHIA.

While ripe oranges are obtainable in Bahia every month in the year, there are two principal seasons, one in June and July and the other in December and January. The June crop is considerably the larger, and the fruits are considered by Bahians much sweeter and juicier than those which ripen in December.

It is difficult to estimate the average yield per tree. The number counted on numerous trees examined at the beginning of the December season varied from a few dozen to nearly 500, with an average of about 250. In groves which had been manured and were generally well cared for, the trees usually carried from 300 to 400 fruits, and this, it must be remembered, does not include the fruit produced in the June crop. Where the trees received good care the yield will probably compare very favorably with that in California. (Pl. V.)

While pruning shears are occasionally used in picking, the fruit is usually pulled from the tree and either allowed to fall to the ground or dropped into a sack. Sometimes the peddlers who come from the city to buy the fruit lead their horses or mules into the grove and toss the fruits from the tree into the large baskets, called "cassuás," strapped on each side of the animals' backs. Frequently the fruits are graded into two sizes before being carried into the city for sale.

Careless picking and handling naturally result in many injuries, such as gravel bruises, abrasions, and punctures of the skin. These must, of necessity, encourage the growth of blue mold and other fungi, but the effect is not so serious as it would be if there were a large export trade and the fruit were held in storage for some time. At present it is picked from day to day to supply the market demands, and very few days elapse before it is consumed.

Oranges are either sold on the tree to peddlers who pick them, carry them to town, and hawk them about the streets, or picked by the orchardist and delivered to the buyer at the grove. Practically all of the crop is carried from the groves to the city, usually a distance of 2 to 4 miles, in baskets, either by horses and mules or on the heads of the natives. The grower usually receives $1.50 to $2 per hundred oranges, and the buyer retails them at about $3.30 a hundred. The local demand is said to be increasing rapidly, and orange culture is proving to be one of the most remunerative agricultural industries. At the present time the best groves are said to be returning net annual profits of $75 to $150 per acre.

An experimental shipment, consisting of a box of 96 fruits, carefully picked and handled so as to avoid bruising, was made from Bahia to Washington, D. C., on January 4, 1914. When examined in Washington on January 27, with the exception of one partly decayed fruit the shipment was in perfect condition. With careful handling and proper facilities for shipping there is little doubt that the Bahia orange can be successfully carried to the leading orange markets of the world. The light greenish yellow color will perhaps make it a slow seller at first, until buyers have learned that it is characteristic of this variety as grown in Bahia.

THE FRUIT OF THE NAVEL ORANGE AT BAHIA.

The navel orange of Bahia has long been known to travelers on the eastern coast of South America, many recent travelers having asserted that it is a fruit vastly superior to the California navel orange. Some declared that its superiority is due to the climate; others affirmed that better types are grown in Bahia than in California, or that since its introduction into North America the navel orange has degenerated.

True it is that there are marked differences in the size, the color, and the quality of the navel oranges produced in these two widely distant regions, though of the same horticultural variety. As to the superiority of one over the other this is a question which can only be decided by individual taste. The navel orange of Bahia (Pl. VI) is large, varying from 3½ to over 4 inches in diameter; yellow green in color, unless very ripe; extremely juicy and sweet, lacking that sprightly subacid flavor which characterizes the California product. The skin is comparatively thin, and, although the flesh is filled with juice, it is not quite so tender as in the California fruit. Those who prefer a sweet fruit would probably choose the Bahia orange as the better; others who relish a slight degree of acidity would give the California product first place.

Analyses made by H. C. Gore, Chemist in Charge of the Fruit and Vegetable Utilization Laboratory, Bureau of Chemistry, United States Department of Agriculture, show the principal differences in chemical composition of 42 navel oranges from Bahia, Brazil, and 13 from Riverside, Cal. Those from Brazil were picked on January 2, 1914, at which time they should have been fully ripe, since they were fruits of the December crop. Those from Riverside, Cal., were picked about the end of March, 1910, and were also fully ripe. The comparison should therefore be a fair one. (Table II).

TABLE II.—*Comparative analyses of navel oranges grown at Riverside, Cal., and at Bahia, Brazil.*

Source of fruit.	Average weight.	Percentage of—		Analysis of juice.							
		Peel.	Rag in pulp.	Specific gravity.	Acid (as citric).	Solids.	Ash.	Alkalinity of soluble ash (K_2CO_3).	As invert. Reducing.	As invert. Sugar.	Sucrose.
Bahia, Brazil:	*Grams.*										
Average of 42 fruits.	366	20.4	1.5	1.0376	0.466	9.4	0.353	0.24	3.43	7.48	3.85
California:											
Hermosa ranch—											
Average of 5 fruits from sandy soil.	199	29.1	1.69	1.0633	1.09	15.47	.51	.23	6.44	12.40	5.66
Average of 4 fruits from adobe soil.	193	31.2	2.04	1.0638	1.09	15.57	.49	.22	6.08	12.72	6.31
Eureka ranch—											
Average of 4 fruits.	235	34.0	1.89	1.0572	1.08	14.06	.55	.18	5.60	10.93	5.07
	210.5	31.2	1.97	1.0585	1.01	14.36	.49	.18	5.41	11.29	5.58

It will be seen from Table II that the percentage of peel or rind is considerably lower in Bahian fruits than in those grown in California. The percentage of "rag," by which term is designated the fibrous matter which remained after all soluble substances were washed out of the pulp, is slightly lower in Bahia than in California.

The most noteworthy features of the chemical analysis of the juice are the low percentage of citric acid and the low percentage of sugar in the Bahian product as compared with that of California.

Table II brings out the difference between humid-climate fruits grown in an equable temperature and those of an arid climate with decided drops in temperature. The dry climate and continuous sunshine of California give the sugar, while the decided drop in winter temperature tends to develop the organic acids and also color.

Decided variation, thought to be bud variation, was observed in every orchard, not only in the fruits but in the vegetative characters of the tree as well. All of the various types originating through bud variation which have been observed and defined in the California orchards, and in addition several new ones, were found to be present in Bahia. The type known in California as the "Australian Navel" orange, characterized by a somewhat corrugated appearance and flattened shape, was observed in several groves. In some cases the production of these fruits was limited to certain limbs on a tree or even to certain fruit spurs; in other cases there were entire trees of this type. "Australian Navel" oranges are inferior in quality, and the great vegetative vigor of the tree is correlated with a poor yield of fruit. Another type was found in which the fruits have a small and almost rudimentary navel. Opposed to this were forms with the navels extremely large and in several instances protruding.

These and other types were studied with the object of determining, if possible, whether there existed in Bahia any navel oranges superior to those already known in California and therefore worthy of introduction into the United States. Bud wood of a number of the most promising of these forms was secured and they are being tested in California and Florida. Because of the important effect of climate on the size and character of the fruit, it is impossible to determine in advance whether types which appear valuable in Bahia will retain their characteristics in the United States. This can only be decided by a trial.

CITRUS FRUITS OF BAHIA OTHER THAN THE NAVEL ORANGE.

In addition to the navel orange there are several other citrus fruits which are cultivated to a limited extent in Bahia. One of the most important of these is the tangerine, grown commercially in a small way, the trees usually being scattered among the orange trees in the orchards. (Pl. I.) The bitter or sour orange (*Citrus aurantium* L.), which already has been mentioned in connection with propagation, is usually represented by one or two trees in each grove, which provide seed for nursery purposes. Sweet and sour lemons and the common lime are occasionally seen, the lime usually being present in the markets in small quantities.

Good grapefruits are unknown in Bahia. A few fruits seen in a garden near the city, which appeared to be inferior forms of the shaddock (*Citrus grandis* (L.) Osbeck), were seedy and thick skinned, and no use was made of them. The so-called "lime orange," laranja lima (*Citrus* sp.), which appears to be more common in Rio de Janeiro, was seen in an orchard at Agua Comprida, about 20 miles from Bahia. It is the size of an ordinary orange, very juicy, and combines the taste of the orange and the lime. The citron (*C. medica* L.) and one or two other citrus fruits are occasionally grown, more as curiosities than anything else.

CITRUS FRUITS OF THE REGION AROUND RIO DE JANEIRO.

There are a number of districts in the vicinity of Rio de Janeiro where citrus fruits, especially oranges, are grown commercially to supply the markets of the city. The most important are Maxambomba, Nictheroy, and the Banca Velha and Porta d'Agua districts near Cascadura.

Maxambomba, 20 miles from the city on the Central Railway, is the largest and by far the most prosperous of these districts. It is difficult to estimate the approximate acreage in oranges, but there are half a dozen groves varying from 5 to 10 acres in extent in the immediate vicinity of the village and others scattered upon the near-by hills (Pl. VII). Most of the groves are better cared for than those seen in the other districts noted above and present a much healthier and more vigorous appearance.

At Nictheroy most of the orange groves are located in the suburb known as Sao Gonçalo, about 4 miles from the center of the city, but easily accessible by means of the electric cars. Here there are numerous small plantations of 1 or 2 acres in extent and a few larger ones. As in the other districts, practically all the groves are located on the hillsides or on sloping ground.

Banca Velha and Porta d'Agua, in a beautiful valley about 12 miles west of Rio de Janeiro, contain numerous small groves and a few several acres in extent. As at Nictheroy, not as much attention is given to the culture of the orchards as at Maxambomba, and the groves do not, as a rule, have a thrifty appearance.

In all these districts the soil appears to be fertile and well suited to orange culture. In the valleys the sandy loam on the surface is sometimes underlain with a subsoil of reddish clay, while on the hillsides the loam is frequently badly washed by the rains. At Maxambomba the reddish clay is visible, the hillsides being of light clay loam.

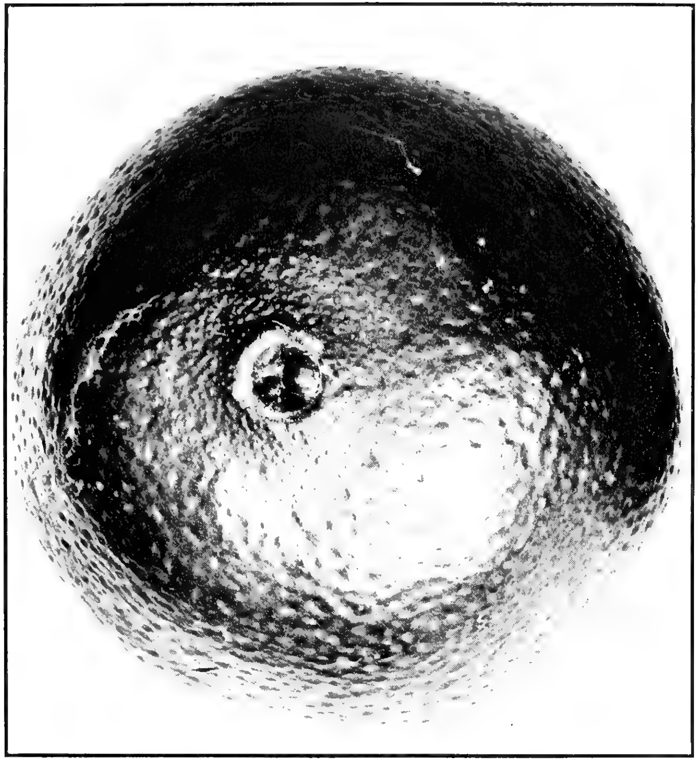
The methods used in propagating and cultivating the trees and in picking and handling the fruit differ in no important respects from those practiced at Bahia. Laranja da terra (*Citrus aurantium*), the bitter or sour orange, is generally used as a stock on which to bud and by most growers is considered the best. The orchards are rarely cultivated, but the surface is cleaned of weeds from time to time with a hoe. The trees, which are often stunted in appearance, are planted closer together than at Bahia, 12 by 12 feet being a common distance.

Of the numerous varieties of the orange known at Rio de Janeiro, only three are cultivated extensively, Selecta, Pera, and Natal, the latter being very similar to Pera if not actually synonymous with it. Many horticulturists at Rio de Janeiro consider Selecta the best

P15309FS

NAVEL ORANGES ON THE TREE.

When well cared for, the trees in Bahia orchards are about as productive as in California, and in place of one crop a year there are two, one ripening from December to February and the other during June and July. The second crop, however, is usually not heavy. The variation in size and character of the navels, even among fruits on the same tree, is clearly shown in this illustration. Photographed in the grove of Col. F. da Costa, Matatu, Bahia, Brazil, December 6, 1913.



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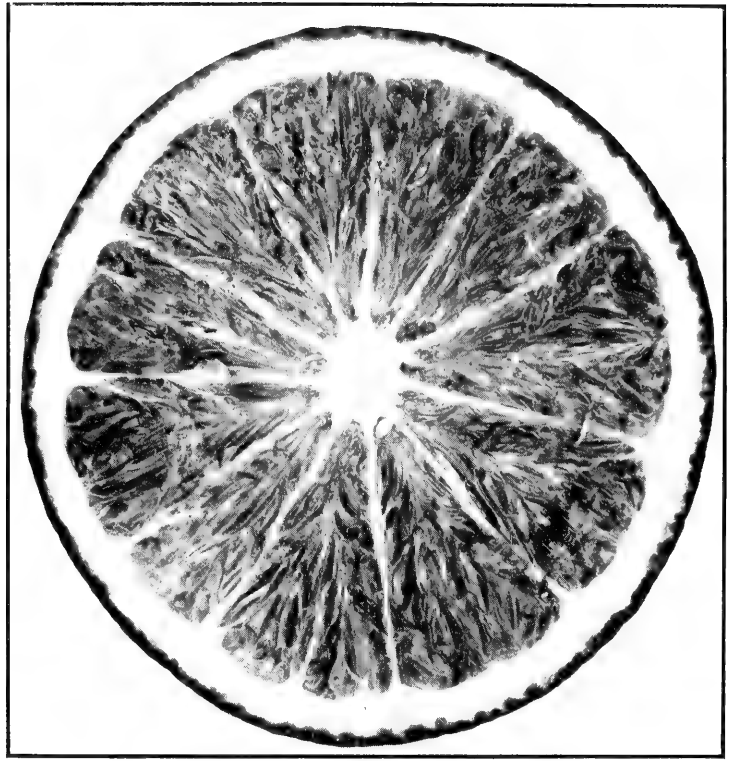


P14421FS

A TYPICAL NAVEL ORANGE AS GROWN AT BAHIA AND A SECTIONED FRUIT OF THE SAME VARIETY.

Fruits considerably larger than this are common in orchards at Bahia, Brazil, but this may be taken as an average specimen. The Bahia navel oranges are sweeter and more juicy than the Washington Navels grown in California, but the flesh is coarser in texture, and the flavor is not so sprightly. The skin is thinner and rarely becomes as brightly colored as it does in the drier climate of California. Photographed November 27 and 28, 1913. (Natural size.)

P15017FS

AN ORANGE ORCHARD AT MAXAMBOMBA, NEAR RIO DE JANEIRO, BRAZIL.

A large part of the oranges sold in Rio de Janeiro are grown in the vicinity of Maxambomba, about 20 miles inland. The soil here is a clay loam, apparently well adapted to citrus culture. The 4-year-old orchard shown in the illustration is planted to the Pera variety, which is the principal one grown in this region. The soil is not cultivated, but is occasionally hoed to keep down the weeds. Photographed March 19, 1914.

P15525FS

A NEW FRUIT, A RELATIVE OF THE CHERIMOYA.

This araticum (*Annona salzmanni*) is found in the suburbs of Bahia. The fruit was previously unknown to science, although specimens of foliage and flowers, from which the species was named, were collected and taken to Europe years ago. The flesh is milky white, sweet, and slightly aromatic. The numerous black seeds are about the size of a common bean. Photographed at Bahia, Brazil, March 12, 1914. (Natural size.)

orange in Brazil. Though not seedless, like the navel orange, its flavor is considered better and the flesh more delicate in texture.

The slightly oblate form of this fruit has given rise to the name laranja deprimida, or "flattened orange," which is sometimes applied to it. In size it is large, though somewhat smaller than the average navel orange of Bahia, measuring 3½ to 4 inches in diameter. The skin is thick, yellowish green in color early in the season, later becoming bright golden yellow. The flesh is tender and very juicy, with tender rag but a rather large, open core. The seeds are rather large, commonly 10 to 20 in number.

In flavor Selecta is strikingly suggestive of the California navel orange; there is more acidity than is normally found in the navel orange produced at Bahia and consequently a more sprightly flavor.

The tree is not as prolific as the other commercial varieties grown at Rio de Janeiro. The fruit commences to ripen early in March and continues until October, the main season being June and July. The relationship between Selecta and the navel orange has already been discussed.

Pera is considered second only to Selecta. It is a smaller and sweeter fruit, coming at the opposite season of the year and thus not competing with Selecta in the market. A good specimen is 3 inches in diameter, slightly elongated in form, but not pyriform as the name laranja da pera, "pear orange," seems to indicate. The skin is smooth and fine in texture, deep golden orange in color, not more than an eighth of an inch in thickness. It adheres closely to the light yellow flesh. The rag, though not thick, is objectionably tough. The juice is abundant and of very sweet flavor, perhaps a trifle lacking in acidity.

In the groves of Maxambomba (Pl. VII) this variety is grown practically to the exclusion of all others. At Nictheroy Selecta is the most prominent, though Natal, "the Christmas orange," which in reality appears to be Pera under another name, is cultivated to a certain extent.

Most of the other citrus fruits found at Bahia are grown also at Rio de Janeiro, the tangerine being especially popular in the Nictheroy district.

MISCELLANEOUS FRUITS GROWN AT BAHIA.

With its rich soil, mild climate, and abundant rainfall Bahia is preeminently suited to fruit culture. That the Brazilians have not been neglectful of this fact is evidenced by the large number of species cultivated, some of them indigenous to the region and others introduced from the Orient by the Portuguese in the early days of colonization. Fruit forms an important item in the diet of the people, and the abundance and variety offered in the markets are a constant surprise to visitors.

With the exception of the orange and the pineapple, of which there are extensive commercial plantations, nearly all fruit trees are grown near the houses and in the gardens of the natives, either as single specimens or in small numbers, frequently crowded together without regard to order. Under such conditions the trees receive very little attention; yet their growth is usually vigorous and their appearance indicative of health.

The Indian tamarind (*Tamarindus indica* L.) is common, the fruit being used principally for making a cooling drink. The carambola (*Averrhoa carambola* L.), another Indian fruit, is also cultivated, but it is not very common. *Phyllanthus acida* (L.) Skeels, known as groselha ("gooseberry"), is seen in many gardens. The avocado, locally called abacate (*Persea americana* Mill.), is one of the most popular of fruits during its season and is cultivated on a commercial scale, one grove alone containing nearly 800 trees. Budding or grafting is not practiced. Among the seedlings none was seen which appeared to be superior to those grown in Florida and the West Indies. The caja and the caja manga (*Spondias lutea* L. and *S. cytherea* Sonnerat) are seen occasionally at Bahia; both are used for making sherbets as well as eaten in the fresh state. The sapodilla, locally known as sapotí (*Achras zapota* L.), grows to large size and its fruit is highly esteemed. Two varieties are distinguished by the natives, one oval or elliptical and the other round. One or more species of Passiflora, known as maracujás, are occasionally seen, as is the jambo, or rose-apple (*Caryophyllus jambos* (L.) Stokes).

The papaya (*Carica papaya* L.), known in Portuguese as mamão, is esteemed as a breakfast fruit. Two forms are distinguished, a small, usually round or oblate type, known simply as mamão, and a large, elongated form known as mamão da India. The latter is considered much the better in quality and always brings a good price in the market. When the fruits are picked it is customary to make four or five shallow incisions through the skin from base to apex and then allow 24 hours or more for the milky juice to exude before the fruit is eaten. This tropical custom is said to improve the flavor of the flesh. Propagation is usually by seed, though in rare instances the mamão da India is said to be grown from cuttings in order to insure its coming true to type.

The common guava of the Tropics (*Psidium guajava* L.), used principally for jelly making, is present in many of the gardens. The manufacture of jelly is carried on commercially, but not on so large a scale as in the State of Pernambuco, farther north. Several indigenous species of Psidium, known as Araça do Rio, Araça cagão, etc., are also grown to a limited extent.

The pineapples of Bahia (called abacaxi in Portuguese) are justly renowned: one author describes them as "mellow and overrunning with juice of incomparable flavor." By the Brazilians they are considered inferior only to those of Pernambuco. During the height of the season they are brought in boatloads across the bay from the mainland and heaped up in large piles at the waterside or in the markets.

The jak of the Malayans (*Artocarpus integra* (Thunb.) L. f.), here known as jaca (jack fruit), which, like the mango, was introduced by the Portuguese in the early days, is not only eaten and appreciated by the lower classes but when abundant is utilized as stock food. Cattle appear to be especially fond of it. The dried pulp, candied, wrapped in tinfoil, and packed in boxes holding about a pound, has recently been put on the market. The fruta de pão, or breadfruit (*Artocarpus communis* L.), is not as common as the jaca, or jack fruit, but is grown in many gardens.

Of annonaceous fruits there are several, of which the most important is the fruta de conde (*Annona squamosa* L.), so named, it is said, because of its having been introduced about the end of the seventeenth century by the Conde (Count) de Miranda. The fruits grown here are of large size and excellent quality. A rare species, *Annona salzmanni* A. DC., usually known under the name of araticum, was seen in several gardens near Cabulla and Retiro. The fruits are about the size of those of the custard-apple (*A. reticulata* L.), with white, rather insipid flesh (Pl. VIII). They are occasionally sold in the market.

A number of other important fruits are grown or occur wild in the region about Bahia. These are described somewhat in detail, since they deserve to be called more particularly to the attention of American horticulturists.

THE GRUMIXAMA.

Among the cultivated myrtaceous fruits the grumixama or grumichama (*Eugenia dombeyi* (Spreng.) Skeels; *Eugenia brasiliensis* Lam.) is one of the most interesting. It is sometimes called the "cherry of Brazil," a term which not inaptly describes its appearance and taste. The tree, 20 to 25 feet in height, is shapely and attractive in appearance, with ovate-elliptical, glossy, deep-green leaves 2 to 3 inches in length. The small white flowers are followed by pendent fruits, round or slightly flattened, about three-fourths of an inch in diameter, glossy, deep crimson in color, crowned at the apex by the persistent green sepals. The thin, delicate skin incloses a soft, melting pulp of mild and agreeable flavor, strikingly suggestive of a

Bigarreau cherry. The seeds are rounded or hemispherical when only one or two are present; sometimes there are three or more, in which case the size is reduced and they become angular.

The rapidity with which the fruits develop is surprising; within a month from the time of flowering they have reached maturity and are falling to the ground. Tavares[1] states that the trees, even of the same variety, do not all ripen their fruit at the same time, some blooming much later than others and thus extending the season from November to February. Three varieties are distinguished, the difference being in the color of the pulp; in one it is dark red, in another vermilion, and in the third white. All three are said to be of equally good quality.

The grumixama is much more common in southern Brazil, particularly in the States of Parana and Santa Catharina, than it is at Bahia. Little attention is paid to its culture, but it is said to prefer a deep and fertile soil. Its propagation is entirely by seed, the trees coming into bearing at 4 or 5 years of age.

The fruit is usually eaten while fresh, but is well adapted to the preparation of various sorts of jams and preserves, in the manufacture of which the Brazilians are unusually adept.

THE PITOMBA.

Another myrtaceous fruit occasionally seen in the gardens of Bahia is the pitomba (*Eugenia luschnathiana* Berg), stated to be indigenous to this region. It is not common in cultivation.

Like the nearly related grumixama, the tree is particularly handsome and worthy of planting for ornamental purposes alone. It attains a height of 20 to 30 feet, with compact, dense foliage, the individual leaves being lanceolate, about 3 inches in length, glossy and deep green above, lighter green on the under surface.

The fruits (Pl. IX), which are borne upon a slender stem about 1 inch in length, are broadly obovate in form, an inch in length, with the apex crowned by four or five green sepals half an inch long. The color is bright orange-yellow. Inclosed by the thin, tender skin is the soft, melting, bright orange-colored flesh, very juicy, aromatic, and of an acid flavor. The seeds, normally one in number, but sometimes two, three, or even four, are rounded or angular and attached to one side of the seed cavity.

The season in Bahia is November and December. The tree as a rule is not so productive as the grumixama or some other myrtaceous fruits, but nevertheless bears a fair crop of fruit.

Propagation is readily effected by means of seed, which appears to be the only method used. Volunteer seedlings spring up abundantly

[1] Tavares, J. S. As fruteiras do Brazil. *In* Broteria, Ser. Vulgar. Sci., v. 10, fasc. 6, p. 420. 1912.

under the trees when fruits remain on the ground. Like nearly all the other myrtaceous fruits observed in Brazil the pitomba seems capable of rapid improvement in the hands of the plant breeder.

THE GENIPAPO.

The genipap of the British West Indies (*Genipa americana* L.), known in Brazil under the name of genipapo, is a close relative of the Gardenia. It is common in Bahia, huge baskets of the fruit being offered in the markets during the months of February and March. While its flavor is rather peculiar and not certain to please a European at first trial, the fruit appears to be quite highly esteemed by the Brazilians and is used by them in various ways.

The tree attains a height of fully 60 feet. It is symmetrical and stately in appearance, but devoid of foliage for a part of the year, as the species is semideciduous. In November it is covered with small yellow flowers. The leaves are a foot or more in length, oblong-ovate, dark green in color, sometimes entire, sometimes more or less dentate. The fruit is the size of an orange, broadly oval to nearly round in form, russet brown in color. After being picked from the tree it is not ready to be eaten until it has softened and is bordering on decay. Immediately under the thin, delicate skin lies a layer of granular flesh a quarter of an inch or more in thickness; within this are the numerous seeds surrounded by yellowish brown pulp. The seeds are compressed, about a quarter of an inch in diameter, and so abundant that it is difficult to eat the pulp without swallowing them. The flavor is characteristic and quite pronounced; it may be likened, perhaps, to that of dried apples, but is stronger, and the aroma is considerably more penetrating.

A liquor which is made from the genipapo retains the distinctive flavor and aroma of the fruit to a marked degree. Its manufacture is carried on commercially in a small way.

A refreshing drink is prepared from the ripe fruit, with the addition of sugar and water. The green fruit yields a dye, which, according to Barbosa Rodrigues, is employed by the Mundurucú Indians for tattooing, and also for coloring clothes, straw, and hammocks.

THE GRAVATÁ.

An oblong straw-colored fruit, known to the natives as gravatá, is occasionally seen in the markets of Bahia. It is a species of Bromelia. It is not cultivated, but occurs wild in this region and is gathered and brought to market by the natives. Its close relationship to the pineapple makes it of peculiar interest. Unlike the pineapple, in which the individual fruits are fused together and form a single whole, the fruits of the gravatá remain separate. They vary in length from 3 to 4 inches, in thickness from an inch to $1\frac{1}{2}$ inches.

They are usually more or less compressed from being crowded together on the stem; a tuft of dry, brown sepals protrudes about an inch beyond the apex. The flesh is crisp, juicy, white, and contains two or three rows of small flattened seeds. The flavor is spicy and delightfully subacid. Care must be taken to remove the skin before eating, however, as it contains a principle which burns the lips and mouth severely. Like the uncultivated types of pineapple, and to a less extent the cultivated ones, it probably contains raphides and also the enzym known as bromelin.

The name gravatá is not limited to this fruit alone, but in Brazil is commonly applied to a large number of bromeliaceous plants.

THE ABÍU.

The abieiro (*Pouteria caimito* (R. and P.) Radlk.), a small tree of the family Sapotaceæ, produces the fruit known as abíu (the suffix "eiro" being added to names of fruits in Portuguese to designate the tree). It is not common in Bahia, but the fruit is seen in the markets in small quantities during February and March.

The tree is pyramidal in form, reaching a height of 15 to 20 feet. The fruit (Pl. X) is egg shaped, 3 inches in length, and externally orange yellow in color. The skin is thick and tough. Surrounding the two or three large oblong seeds is the translucent, white flesh, of delicate flavor, resembling that of the sapodilla (*Achras zapota* L.). Unless fully ripe it contains a milky fluid which coagulates on exposure to the air and sticks to the lips in an annoying manner.

The abíu appears to be used only as a fresh fruit. It is, perhaps, more popular at Rio de Janeiro than at Bahia, though its cultivation is not extensive at either place. At Para it is said to be one of the commonest fruits.

THE PITANGA.

The pitanga (*Eugenia uniflora* L.), known in southern Florida as Surinam cherry, is widely grown in Bahia as a hedge plant. It seems admirably adapted to this use, forming a compact, bright-green hedge, thickly foliaged from the ground up. It produces small, oblate, ribbed fruits, deep crimson in color and about an inch in diameter; when grown as a hedge, however, the plants do not bear as heavily as when given more room and allowed to develop unhindered. The small, ovate, glossy green leaves are frequently scattered over the floors of the houses, yielding, when bruised by trampling, an agreeable spicy odor, which is much liked and thought to be efficacious in driving away flies.

THE CASHEW, OR CAJÚ.

One of the most abundant and popular fruits is the cashew, or cajú (*Anacardium occidentale* L.), of which there are innumerable wild trees in the immediate vicinity of the city. The tree is practically never planted, and so far as could be learned no effort is being made to select and propagate the better types. Quantities of the fruits are gathered from wild seedling trees and brought into the market, where their aromatic fragrance soon dominates all other odors. The island of Itaparica, in the bay of Todos os Santos, about 7 miles from the city, is said to produce the finest cashews. One tree on the island, the "Manteiga" or "butter" cashew, is especially famed. Aside from being eaten fresh, in which state great quantities are consumed by the natives, the cashew makes excellent jams and jellies and a light wine, all of which are manufactured commercially.

THE MANGO.

The mango (*Mangifera indica* L.), introduced from India in the early days, vies in popularity with the cashew, though it is not produced in such lavish profusion. Large seedling trees are seen everywhere, not only in gardens, but along the roadsides wherever seeds have chanced to fall. The immense size which the tree attains in the deep soil of this region is astonishing; a magnificent specimen at Cabulla (Pl. XI), said to be over 100 years old, was found to have a spread of 120 feet, while the trunk was over 25 feet in circumference.

Itaparica is famed throughout Brazil for its mangos. Most of the trees on the island are seedlings, of which more than 180 are known by name. Quantities of fruit are exported to Rio de Janeiro, the growers receiving \$5 to \$10 per hundred. At this rate, some of the largest trees are reported to yield an annual income of \$200.

It must be admitted that most of the mangos grown in Bahia and elsewhere in Brazil, grafted varieties as well as seedlings, are somewhat inferior to the best of those cultivated in India, the Philippines, or the United States. There is one variety, however, whose unusual beauty and exceptional commercial qualities make it of particular interest. This is the Manga da rosa (rose mango), grown commercially in the vicinity of Pernambuco and to a less extent at Bahia, Rio de Janeiro, and other points in Brazil. During the holiday season quantities of the fruit are shipped to Rio de Janeiro, principally from Pernambuco, and sold by dealers in fancy fruits at the equivalent of 65 to 80 cents each. The attractiveness of this mango, with its cordate, regular form, slightly beaked at the apex, and its contrasting shades of apricot and scarlet, can scarcely be resisted. It will average about 1 pound in weight. The fiber is coarse and rather long; the quality is fair; the flavor and aroma are very good, indeed. However, the variety as a whole can not be considered the equal of the Mulgoba, Paheri, or several other Indian mangos grown in the United States. Its unusual attractiveness and the fact that it withstands shipment and handling much better than other varieties observed make it of interest and well worthy of introduction for experimental tests in North America.

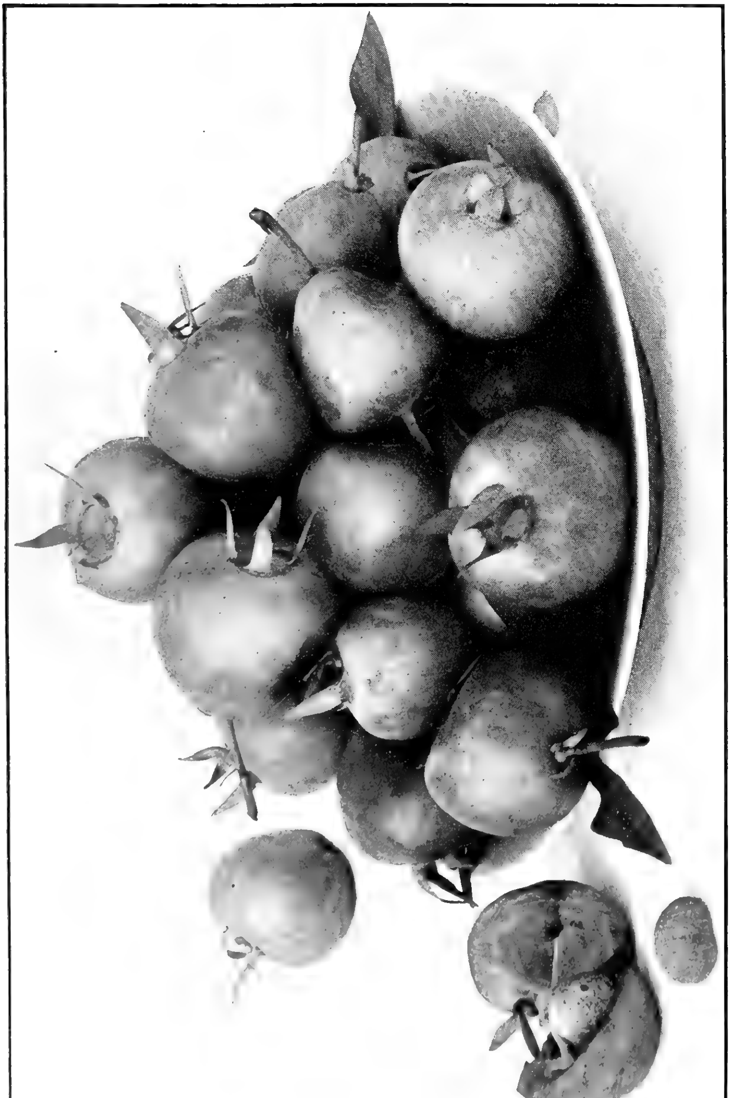
Manga da rosa is believed to have been introduced into Brazil from Mauritius. Two subvarieties are known in Bahia, "da terra" and "do Rio," differing slightly in the shape of the fruits. Inarched trees are produced in small quantities and sell at $3 each. The variety is polyembryonic, like the "No. 11" mango of Florida and the West Indies, and appears to be a regular and prolific bearer.

There are four other named varieties of the mango which are propagated by grafting and are more or less well known at Bahia as well as in other sections of Brazil. The best of these is probably the Itamaraca, which takes its name from the island of Itamaraca, off the Brazilian coast near Pernambuco, a place especially noted for its mangos. The fruit is small and of very unusual form, distinctly oblate, with a small protuberance, or "nak," at the stigmatic point near the apex. Usually it does not average more than 3 inches in diameter. Its color is orange yellow, and the flesh is free from fiber, is aromatic, and of piquant, spicy flavor. It is generally considered the best flavored of the grafted varieties. Espada (sword), another named variety, is apparently a seedling type, of which individuals are sometimes propagated by inarching. Its form is distinctive, long and curved at each end. It is usually yellowish green when ripe, not at all attractive in appearance. While its flavor is fair, the flesh is very fibrous and it must be ranked as inferior. Carlota and Augusta and two other named varieties, neither of them being widely grown. Both are rather small, of good flavor, but with no particular merit.

THE DENDÉ PALM.

The Guinea oil palm (*Elaeis guineensis* Jacq.), known in Bahia as dendé, was doubtless introduced from Africa in the early days of the slave trade. It is frequently seen growing upon the hillsides on the edge of the city and is common around the huts of the negroes. Its tall, straight stem, ascending to a height of 40 or 45 feet, is crowned by a rather compact head of stiff, pinnate leaves about 20 feet in length. While not graceful in appearance, it is handsome and of considerable ornamental value, the scattered groups, which are abundant in the suburbs, being among the most pleasing features of the landscape.

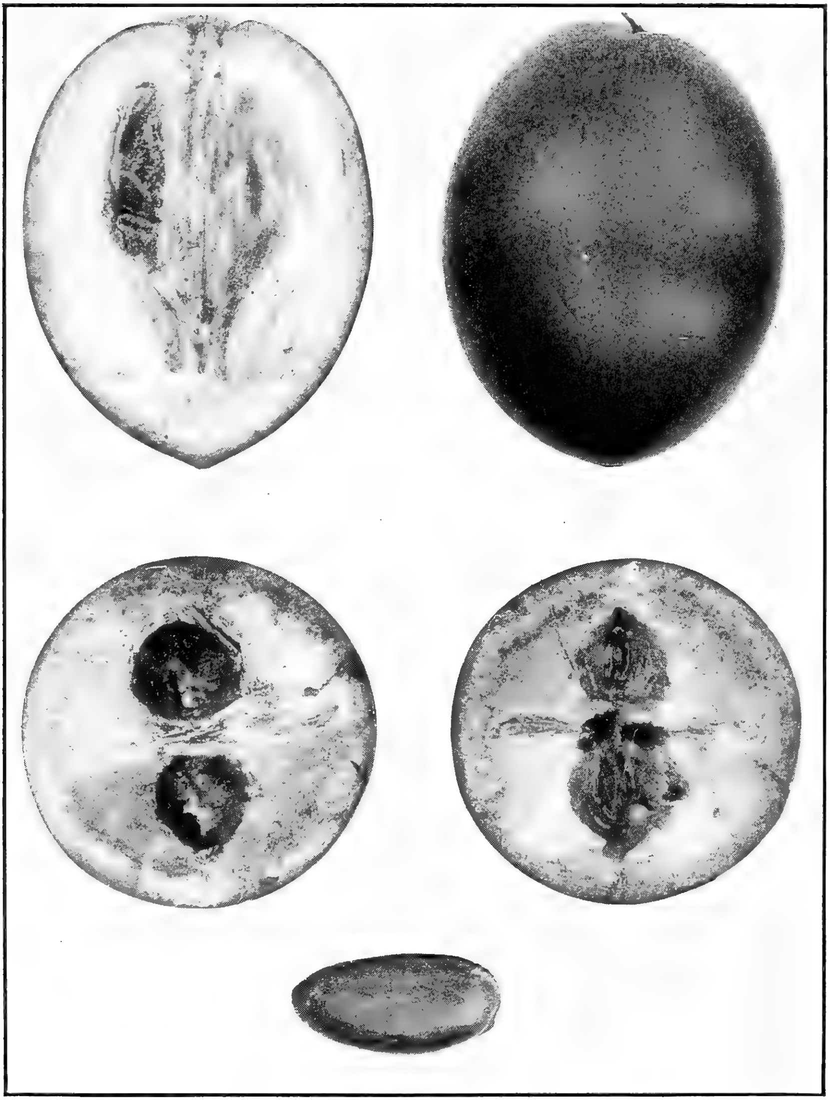
The fruits are produced in crowded bunches, clustered around the trunk at the bases of the leaves. Individually they are oblong elliptical, about 2 inches in length and 1 inch in thickness, dull orange-scarlet in color when fully ripe. The large seed is surrounded by a layer of firm golden yellow pulp, very rich in oil.



P15400FS

THE PITOMBA, AN INTERESTING RELATIVE OF THE GUAVA.

The pitomba (*Eugenia luschnathiana*) is found in the vicinity of Bahia, Brazil. The fruit is golden yellow in color, sharply acid, with a pleasant flavor and spicy, aromatic fragrance. It is sometimes eaten fresh, but more frequently made into preserves and jelly. Photographed at Bahia, Brazil, December 21, 1913. (Three-fourths natural size.)



P14973FS

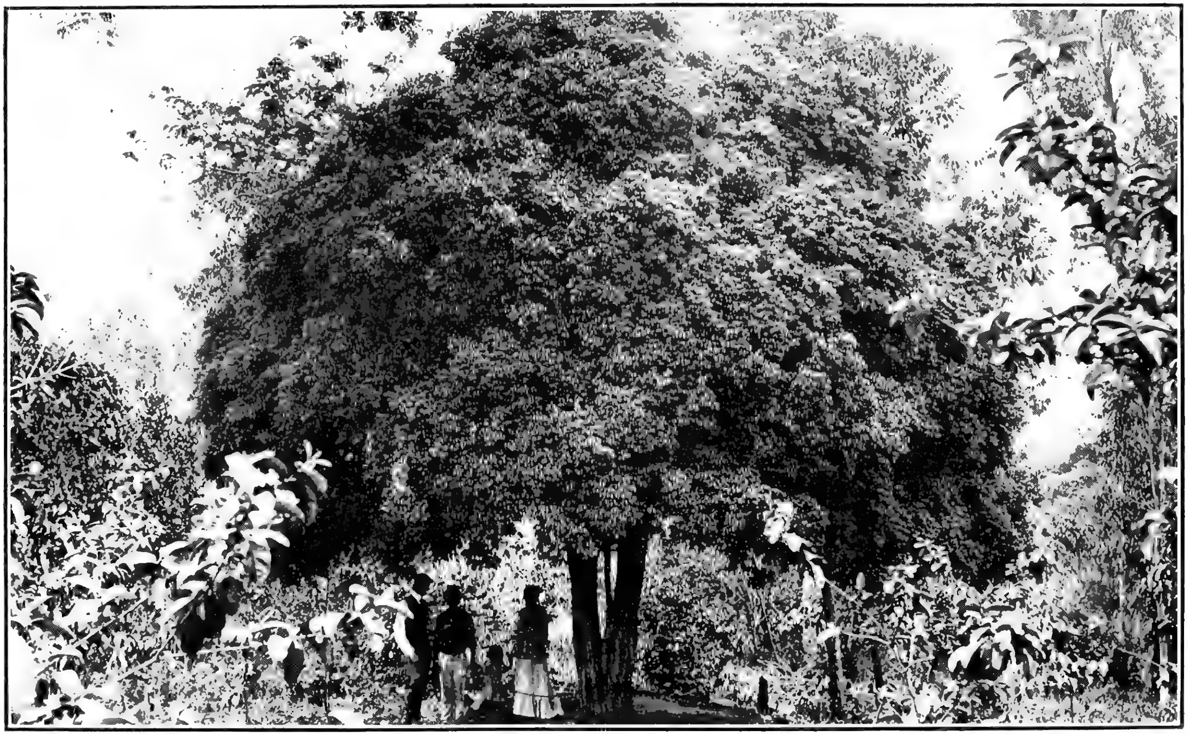
THE ABÍU, A FRUIT RESEMBLING THE SAPODILLA.

This tree is comparatively rare in tropical America, but it is cultivated at Bahia, Rio de Janeiro, and other places in Brazil. The fruit is bright yellow in color, with white flesh of a sweet, rich flavor, strongly suggesting that of the sapodilla (*Achras zapota*), to which it is related. The tree is small and of very attractive appearance. Botanically it is known as *Pouteria caimito*. Photographed at Bahia, Brazil, November 3, 1913. (Natural size.)

P15374FS

AN UNUSUALLY LARGE MANGO TREE AT CABULLA, BAHIA.

On the deep, fertile soil of this region the mango attains immense proportions. The specimen shown in this photograph is believed to be over a hundred years old. It is 25 feet in circumference and at noonday casts a shadow 120 feet in diameter. This large seedling mango occasionally bears a good crop of fruit of fair quality. Photographed at Col. Lago's, Cabulla, Bahia, Brazil, December 12, 1913.



P15112FS

THE JABOTICABA TREE (MYRCIARIA CAULIFLORA).

A good specimen of this remarkably interesting tree is shown in this illustration. Its compact symmetrical head of small bright-green leaves makes it very attractive. The jaboticaba grows wild in southeastern Brazil and is also cultivated to a greater extent than almost any other native fruit. Photographed at Sr. A. G. Fontes's, Porta d'Agua, Rio de Janeiro, Brazil, October 28, 1913.

Dendé oil is an important food product, entering into the preparation of a number of dishes, some of which, such as vatapá, are considered peculiar to the region. While utilized by all classes of people, its greatest popularity is among the negroes, long familiarity having made dendé oil almost as indispensable to them as olive oil is to the Spaniard. The price at which it is sold, 25 to 30 cents for a quart bottle, is not high by Brazilian standards. Its flavor is characteristic, but not objectionably strong. The oil is prepared by a simple process, requiring no special utensils and involving but little labor. The pulp is macerated and placed in cold water, and as the oil rises to the surface it is skimmed off, placed in a pan, and boiled down to remove all water and other foreign substances. When ready for use it is deep orange colored, about as heavy as olive oil, and usually somewhat cloudy in appearance. Upon exposure to cold it solidifies. It is said to be employed as an illuminating oil, as well as being used for culinary purposes.

The utility of the dendé palm is not limited to the production of oil. Among the Bahians the leaflets are used for making brooms, while the woody leafstalks are split and woven into baskets.

SOME INTERESTING FRUITS OF RIO DE JANEIRO AND VICINITY.

Aside from the natural beauty of its surroundings, the capital of Brazil has an added interest to the horticulturist in its magnificent avenues of Royal palms (*Oreodoxa oleracea* Mart.), of which there are a number scattered throughout the city. In such an avenue as that in the Botanic Garden, over half a mile in length, this palm is seen at its best, its straight, flawless trunk rising to a height of over a hundred feet, crowned by a tuft of graceful leaves. There are certainly few plants more striking in landscape effect than this, and it should be more widely grown throughout the Tropics and in the United States wherever it will survive the winters.

Rio de Janeiro does not appear to have the profusion of indigenous and exotic fruits which are found in Bahia, yet the markets are nearly always supplied with many choice sorts. European fruits, such as the apple, the pear, and the grape, hold a much more important position than in Bahia, large quantities being imported from Europe and North America in addition to a limited production of certain ones in various parts of southern Brazil. Many of the tropical fruits found at Bahia are common, notably the cashew, the mango, the sugar-apple, the pineapple, and the banana.

THE JABOTICABA.

Among the fruit trees cultivated in the gardens about Rio de Janeiro the jaboticaba is one of the commonest, and certainly the one which creates the strongest impression upon the newcomer. The peculiar habit of producing its delicious fruit directly upon the bark of the tree, not only upon the small limbs but upon the trunk and it is said even upon exposed roots, together with the unusual beauty of its symmetrical, dense, umbrageous head of light-green foliage, places it far above the average indigenous fruit tree of tropical and subtropical South America.

The jaboticaba is extremely popular and highly esteemed by all classes of Brazilians. It has been cultivated for generations, yet in spite of this fact, it is, botanically speaking, but imperfectly known. Horticulturists generally list it as *Myrciaria jaboticaba* Berg, but Berg himself distinguished and defined three distinct species, *M. cauliflora*, *M. trunciflora*, and *M. jaboticaba*, whose fruits are all known under the name of jaboticaba. Tavares,[1] in describing these three species, states that they can only be distinguished when growing wild in the forests, since culture produces marked variation from the typical characters and in addition some of the cultivated forms are the results of crosses between the different species. It can easily be seen, therefore, that in studying the trees found in cultivation and attempting to name them accurately, many obstacles are encountered.

The geographic distribution of the jaboticaba is stated by the best authorities to be from Rio Grande do Sul on the south to Minas Geraes on the north and from the coast to Goyaz and Matto Grosso on the west. Outside of this region the tree is occasionally seen in cultivation, as at Bahia, where it does not appear to thrive and is rarely grown. Around Rio de Janeiro it is one of the features of gardens and orchards. Not only are there single trees in many gardens, but occasional small plantations an acre or two in extent.

The zone of the jaboticaba extends from sea level to altitudes of 3,000 feet, or even more. At Petropolis it grows and fruits well, according to Tavares,[2] and at Barbacena, in Minas Geraes, where the altitude is 1,168 meters, it seems to thrive, although the winters are sometimes very cool. In this section of Brazil, however, ice rarely forms, even at such altitudes.

At Lavras, Minas Geraes, nearly every garden contains one or more trees, making the jaboticaba easily the most important fruit of the region. At Pirapora, head of navigation on the Rio Sao Francisco, there are a few gnarled and stunted trees whose abnormal condition apparently indicates that they are near the edge of the zone in which the tree can be grown.

One of the greatest Brazilian botanists, Barbosa Rodrigues, considered the jaboticaba (Pl. XII) the handsomest of all the Myrtaceæ. Under favorable conditions it reaches a height of 35 or 40

[1] Op. cit., v. 10, p. 422.

[2] Op. cit., v. 10, p. 429.

feet, the trunk branching freely close to the ground. The leaves are persistent, opposite, ovate-elliptical to lanceolate, acute at the apex, generally glabrous, with the margins entire. In length they vary from three-fourths of an inch to over 3 inches, their size being one of the principal characteristics by which the natives distinguish the different horticultural forms which are cultivated in the gardens. The flowers (Pl. XIII) are small, white, produced singly and in clusters on the bark from the base of the trunk to the ends of the small branches, sometimes so thick as almost to hide the trunk, limbs, and small branches from view; in form they resemble those of the myrtle, having four small white petals and a prominent cluster of white stamens. The season of flowering varies greatly with the different species and in different localities.

The fruit (Pl. XIV) develops very rapidly and is ripe two or three months after the appearance of the flowers. In form it is round or slightly oblate, half an inch to an inch and a half in diameter, deep, glossy maroon-purple in color, crowned with a small disk at the apex. While sessile in *Myrciaria cauliflora*, in *M. jaboticaba* the fruits are produced upon slender stems about an inch in length. Those of *M. cauliflora* are considered the largest, frequently averaging an inch or more in diameter as seen offered for sale in the markets. The skin is thick and rather tough; besides coloring matters it contains a large amount of tannin. The translucent, juicy pulp, white or tinged with rose, is of a most agreeable, vinous flavor, suggestive of the Scuppernong or Muscadine grape (*Vitis rotundifolia*) of the Southern States; the whole appearance and character of the fruit so suggest a grape, in fact, as to earn for the jaboticaba the name of "the grape of Brazil." One not infrequently finds a jaboticaba with the disagreeable resinous twang common to a number of myrtaceous fruits. This may be due in many instances to the condition of the fruit at the time of eating or to the inferiority of the particular variety. A good jaboticaba is so thoroughly enjoyable as to tempt one to keep on picking and eating the fruits indefinitely. Brazilians are wont to yield to this temptation, especially the children, who spend hours searching out and devouring the ripe fruits, their only complaint being that it is impossible to satisfy one's appetite with jaboticabas.

The seeds, which vary from one to four in number, are not easily separated from the pulp. In form they are oval to almost round, compressed, and about a quarter of an inch in length.

A number of named varieties are known to the Brazilians, some of which are probably true species, others horticultural forms originating through seedling variation. The name jaboticaba, without any qualifying word, is considered to be properly applied only to

Myrciaria cauliflora. The species jaboticaba is properly known as jaboticaba de Sao Paulo, jaboticaba de cabinho, and jaboticaba do matto. Tavares[1] mentions another species, *M. tenella* Berg, whose fruit is known as jaboticaba macía. The horticultural variety Corôa, one of the commonest named forms in Rio de Janeiro and Minas Geraes, can probably be referred to *M. cauliflora.* Another variety, Murta, is equally well known, and has smaller leaves than Corôa; it, too, is possibly a form of *M. cauliflora.* Branca (white) and Roxa (red) are two other names that are occasionally applied to varieties cultivated in the gardens.

When heavily laden with fruit the tree is a curious and interesting sight (Pl. XV). Not only is the trunk covered with clusters and masses of glistening jaboticabas, but the fruiting extends to the ends of the smallest branches as well. When one stops to consider the comparatively small size of the fruits and the profusion with which they are produced all over the tree, it is apparent that the number must be enormous.

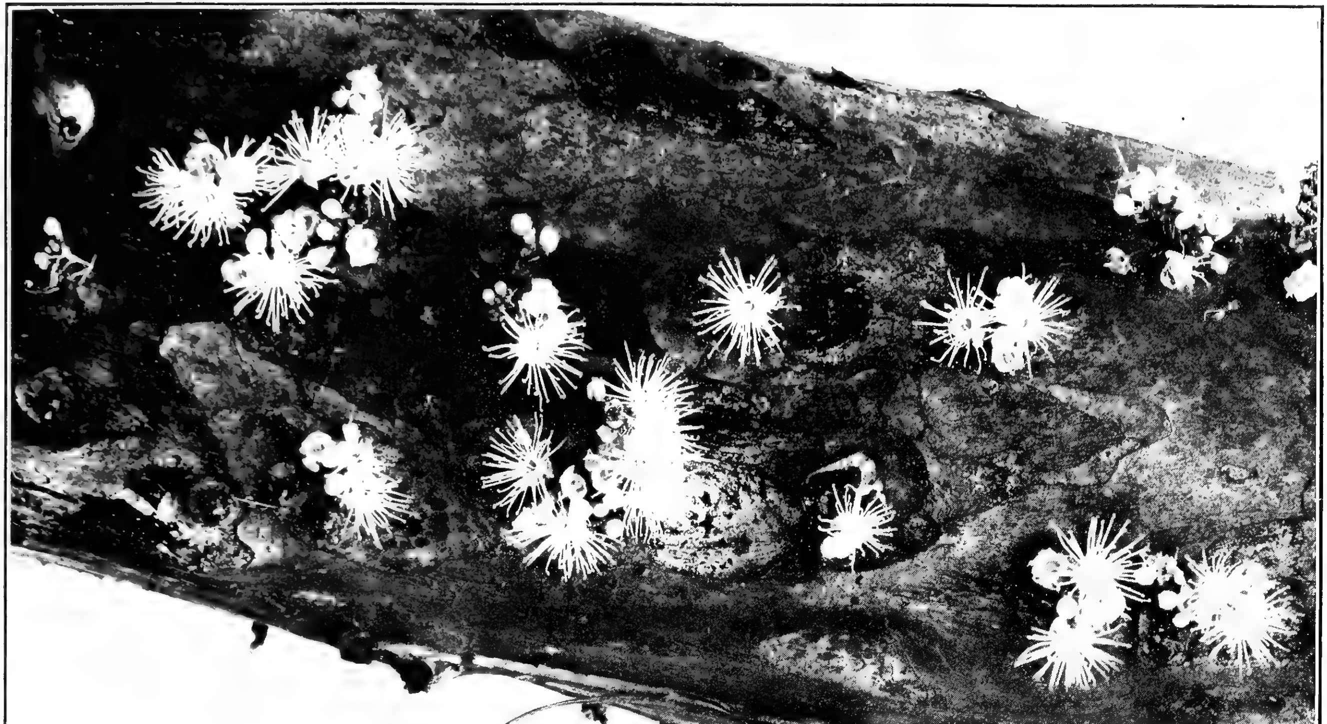
The season not only varies with the species and location, but quite frequently several crops a year are produced. The trees even flower and fruit during the winter months in locations where the temperature does not go below 64° F. Tavares[2] considers moisture to be the essential factor governing fruit production and states that the fazendeiros (ranchers) of Sao Paulo, who irrigate their trees at times when there is a scarcity of rain, succeed in having ripe jaboticabas throughout the year.

For shipping, the fruit is usually packed in wooden boxes which originally held two 5-gallon cans of kerosene. No packing material is used, and on account of the quantity of fruit in a single package much of it, of course, is crushed and bruised. Since good jaboticabas are sold in Rio de Janeiro for the equivalent of 25 cents a pound there is sufficient profit in handling the fruit to permit its being shipped from considerable distances. Boxes from Sao Paulo and the interior of Minas Geraes are sometimes seen in the markets of Rio de Janeiro.

While the jaboticaba is adapted to a number of different uses, at the present day practically all of the fruit seems to be consumed in the fresh state. By the aboriginal inhabitants a wine was made, which was held in high esteem. Recently the manufacture of jaboticaba jelly has been taken up with very successful results. It has been found that the skins should be removed from about half the fruits used in order to prevent the jelly from having too strong a taste of tannin.

The tree succeeds best in a deep and rich soil, although it seems to grow on heavy clay or poor soils when forced to do so. Its growth

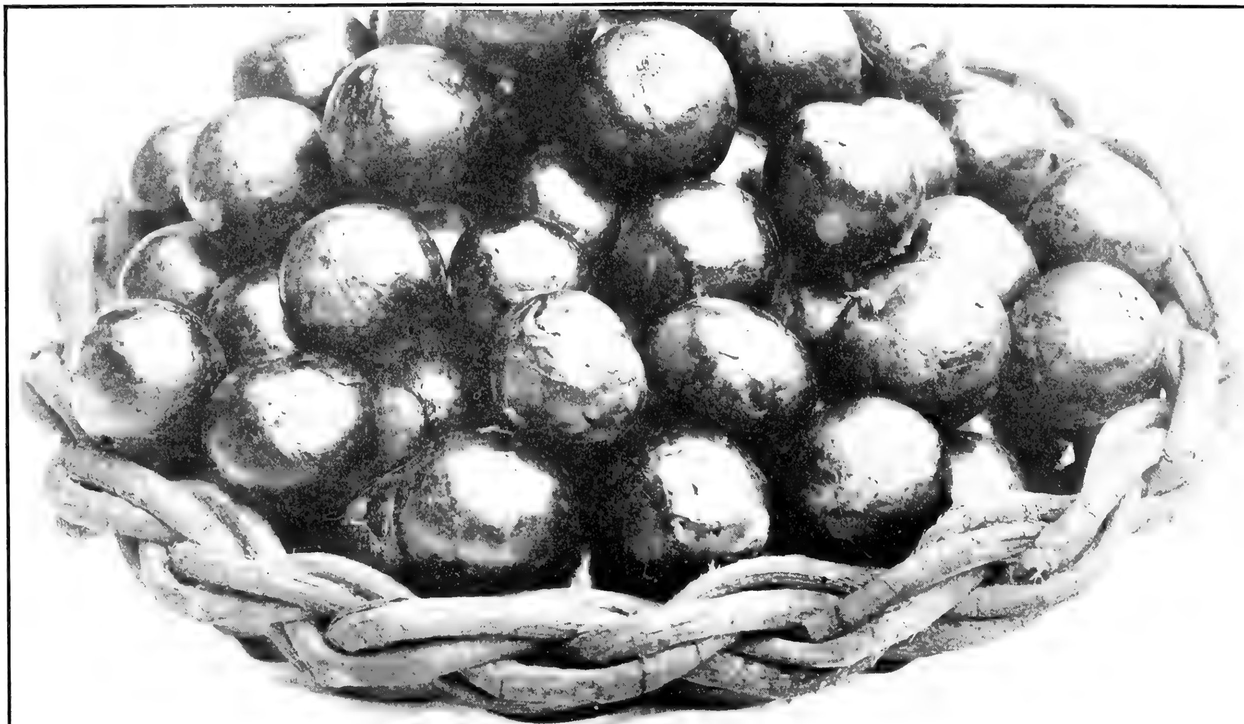
[1] Op. cit., v. 10, p. 429. [2] Op. cit., v. 10, p. 427.



P16438FS

SECTION OF A MAIN BRANCH OF THE JABOTICABA TREE IN FLOWER.

The flowers of the jaboticaba are produced directly on the trunk and main branches as well as on the smaller branches and twigs. In one species the fruits are sessile; in another they have short stems. At times the flowers and later the fruits almost hide from view the trunk and large branches and limbs. Photographed at Lavras, Minas Geraes, Brazil, January 20, 1914. (Natural size.)



P14382FS

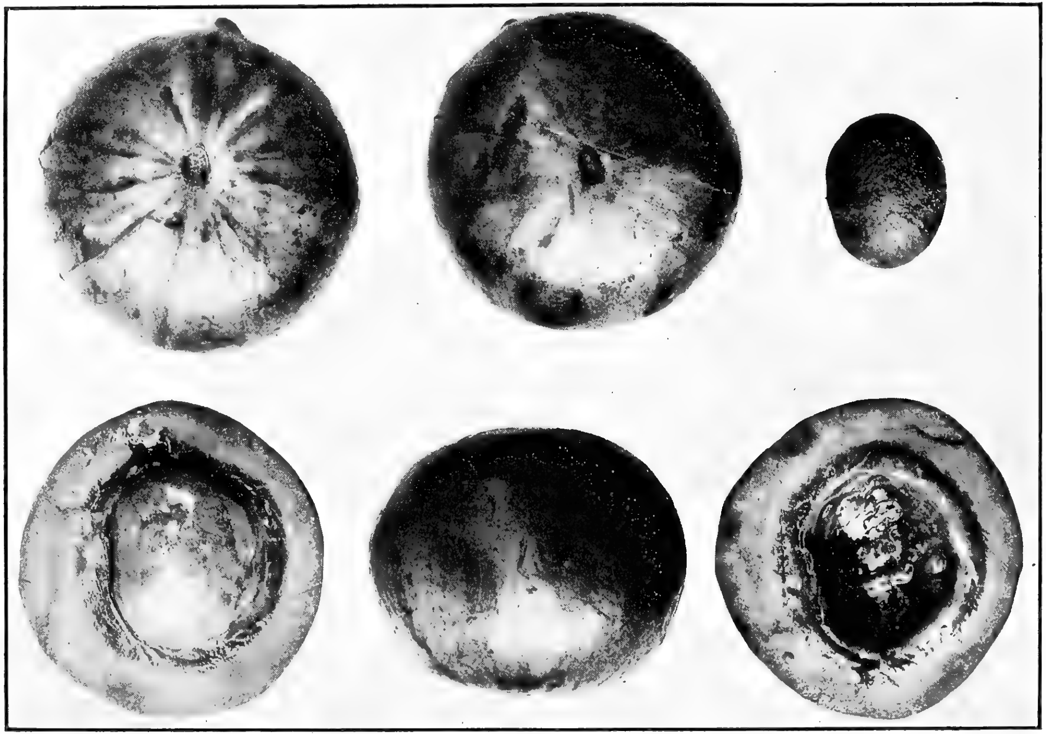
A BASKET OF JABOTICABAS.

Inclosed by a tough skin is a mass of white, translucent, juicy pulp with one to four medium-sized oval seeds. Their strong resemblance in flavor, character, and general appearance to certain types of grapes has suggested the name "grape of Brazil," by which the jaboticaba is sometimes called. Photographed at Rio de Janeiro, Brazil, October 24, 1913. (Natural size.)

P15123FS

THE FRUITING LIMBS OF A JABOTICABA TREE.

The clusters and masses of glistening purple fruits scattered over the smooth bark of the trunk and main branches of the jaboticaba tree are a novel and interesting sight. Sometimes two or even three crops are produced in a year. Photographed at Sr. Catramby's, Porta d'Agua, Rio de Janeiro, Brazil, October 28, 1913



P15409FS

THE CAMBUCÁ, A NEAR RELATIVE OF THE JABOTICABA.

Like the jaboticaba, this Brazilian fruit (*Myrciaria edulis*) is produced directly upon the trunk and main branches of the tree. It is bright orange in color and of a sprightly, subacid flavor. The tree grows in the forests about Rio de Janeiro and is sometimes seen in gardens. Photographed at Rio de Janeiro, Brazil, January 1, 1914. (Three-fourths natural size.)

is slow, from six to eight years being required for it to come into bearing. While doubtless hardier than many of the strictly tropical fruits, it withstands but little frost. Its advantage seems to be, however, that it thrives in regions where the winters are normally too cool for the successful culture of such fruits as the jak (*Artocarpus integra*) and the cashew, which come from strictly tropical regions.

Its propagation seems to be exclusively by seed, though inarching is said to be practicable. Some vegetative means of propagation must be employed if improved varieties are to be established and perpetuated.

THE CABELLUDA.

This myrtaceous fruit (botanically *Eugenia* (*Phyllocalyx*) *tomentosa* Cambess.) is not common in gardens around Rio de Janeiro, although indigenous to the region. While an occasional tree is seen, it does not compare in popularity with either the jaboticaba or the pitanga.

When well grown the tree is handsome and would be of value as an ornamental alone. It reaches a height of 15 to 25 feet, with a broad dome-shaped head of foliage. The leaves are 2 to 4 inches in length and about 1 inch in breadth, oblong lanceolate, bright green and slightly tomentose above, dull green and tomentose below.

The name cabelluda is the feminine of the Portuguese adjective meaning hairy and has reference to the downy tomentum present on both the leaves and the fruits. The tree flowers in June and the fruits ripen in October and November. They are sessile and produced on the small branches in great numbers, somewhat resembling large gooseberries in appearance, but when fully ripe are bright golden yellow in color. The largest specimens are slightly under an inch in diameter, round or nearly so, and the skin is firm and tough. The pulp is rather scanty, but juicy and of pleasant subacid flavor, suggesting the May-apple (*Podophyllum peltatum* L.) of the United States. The one or two large seeds are surrounded with coarse but very short fibers.

THE GUABIROBA.

Another interesting myrtaceous fruit is the guabiroba (*Campomanesia fenzliana* (Berg) Glaziou), whose foliage is remarkably similar to that of some of the European oaks. It is indigenous in the forests of Rio de Janeiro State and is cultivated to a limited extent in gardens.

The name guabiroba is also applied, with various orthographical changes, such as gabiroba and guabiraba, to several other fruits of the genus Campomanesia, some of which are common on the campos or open plains of Minas Geraes.

The tree occasionally reaches a height of 30 or 40 feet. Its leaves are elliptical-ovate in form, entire, about 2 inches in length, the veins depressed above and prominent below. The fruits greatly resemble small guavas; they are three-fourths of an inch or more in diameter, oblate in form, the apex crowned by a large disk and five persistent sepals. When fully ripe they are orange yellow in color, the surface slightly wrinkled longitudinally and covered with a thick tomentum or down. The skin is thin and surrounds a layer of granular, light-yellow flesh, which incloses the seeds and the soft pulp in which they are embedded. The flavor is similar to that of a guava, but frequently stronger.

According to Tavares[1] there are four varieties of this species, but they are not well known. The principal use to which the fruits are put is the manufacture of jellies.

THE CAMBUCÁ.

Botanically the cambucá is referred to *Myrciaria plicato-costata* Berg, correctly known as *M. edulis* (Vell.) Skeels, but Barbosa Rodrigues believed there was some confusion within the species.

Like the guabiroba, this fruit is indigenous to the vicinity of Rio de Janeiro and is also cultivated in gardens. In general appearance both the tree and the fruit are suggestive of the jaboticaba. The leaves are somewhat larger, however, and the bark a darker shade of brown.

While cauliflorous and sessile, the fruits (Pl. XVI), which are commonly eaten fresh, are not produced in such profusion as jaboticabas, nor are they found as a rule on the lower part of the trunk. In form they are oblate, an inch and a half in length and 2 inches in breadth, with a small brown disk not over an eighth of an inch in diameter at the apex. The skin is smooth, orange yellow in color, and rather tough. The soft, translucent inner flesh only is edible; between it and the skin is a thick, tough layer, bright orange in color, which has to be discarded with the skin. The flavor is subacid, greatly resembling some of the Passifloras, very pleasant and agreeable, though perhaps not so delicious as that of the jaboticaba. The seed is oval, seven-eighths of an inch in length, and is easily separated from the flesh.

THE BACUPARÍ.

This is a beautiful pyramidal tree (*Rheedia brasiliensis* Planch. and Triana) of the family Clusiaceæ, indigenous to the State of Rio de Janeiro. As indicated by the name it greatly resembles the bacurí (*Aristoclesia esculenta* (Arruda) Stuntz; *Platonia insignis* Mart.). It is smaller in size, and while not considered quite so

[1] Op. cit., p. 36, 1913.

delicious is highly esteemed by the natives, especially in the form of a doce or jam, when, as one writer says, "it is a nectar."

In form the bacuparí is ovate, rather sharp at the apex, varying in length from an inch and a quarter to an inch and a half. The stem is 1 to 2 inches in length, rather stout. The tough, pliable, orange-yellow skin, about an eighth of an inch in thickness, surrounds the soft, translucent, snowy white pulp in which two oblong, elliptical seeds are embedded. In flavor the pulp is subacid, sprightly, suggestive of the mangosteen, to which it is distantly related. When fully ripe it is delicious.

The tree is said to flower in December and ripens its fruit in January and February. It is little known in cultivation.

THE FRUTA DE CONDESSA.

During March and April the fruta de condessa (*Rollinia deliciosa* Safford) is not rare in the markets of Rio de Janeiro. Large baskets of the fruit are shipped in from the near-by regions and offered alongside its relative, the sugar-apple (*Annona squamosa* L.), called locally fruta de conde, frequently at a higher price than the latter.

In general form this fruit (Pl. XVII) is conical to cordate, sometimes even oblate, and 3 to 4 inches in diameter. The surface is covered with conical protuberances arising from the carpellary areas and is creamy yellow in color. The skin is rather tough and not easily broken; it surrounds the milky white, somewhat mucilaginous flesh in which the seeds are embedded. The flavor is sweet, and it is relished by the Brazilians, as evidenced by the quantity of fruit sold. The seeds are not as numerous as in many other annonaceous fruits and are about the size of an average bean.

FRUITS OF THE HIGHLANDS AND SEMIARID REGIONS OF MINAS GERAES AND BAHIA.

A large number of wild fruits are found on the rolling plains of the State of Minas Geraes, some of them having been brought under cultivation by the inhabitants of this region. In addition to the common fruits of the Tropics, the higher portions of Minas Geraes produce some of the European fruits and the North American grapes quite successfully. As there is an extensive demand for peaches, plums, apples, pears, and other temperate fruits in Rio de Janeiro and other large cities, the Brazilian Government has recently established an experiment station in connection with the agricultural school at Barbacena (Pl. XVIII), where numerous varieties of all the more important temperate fruits are being tested in order to find which are best adapted to the region.

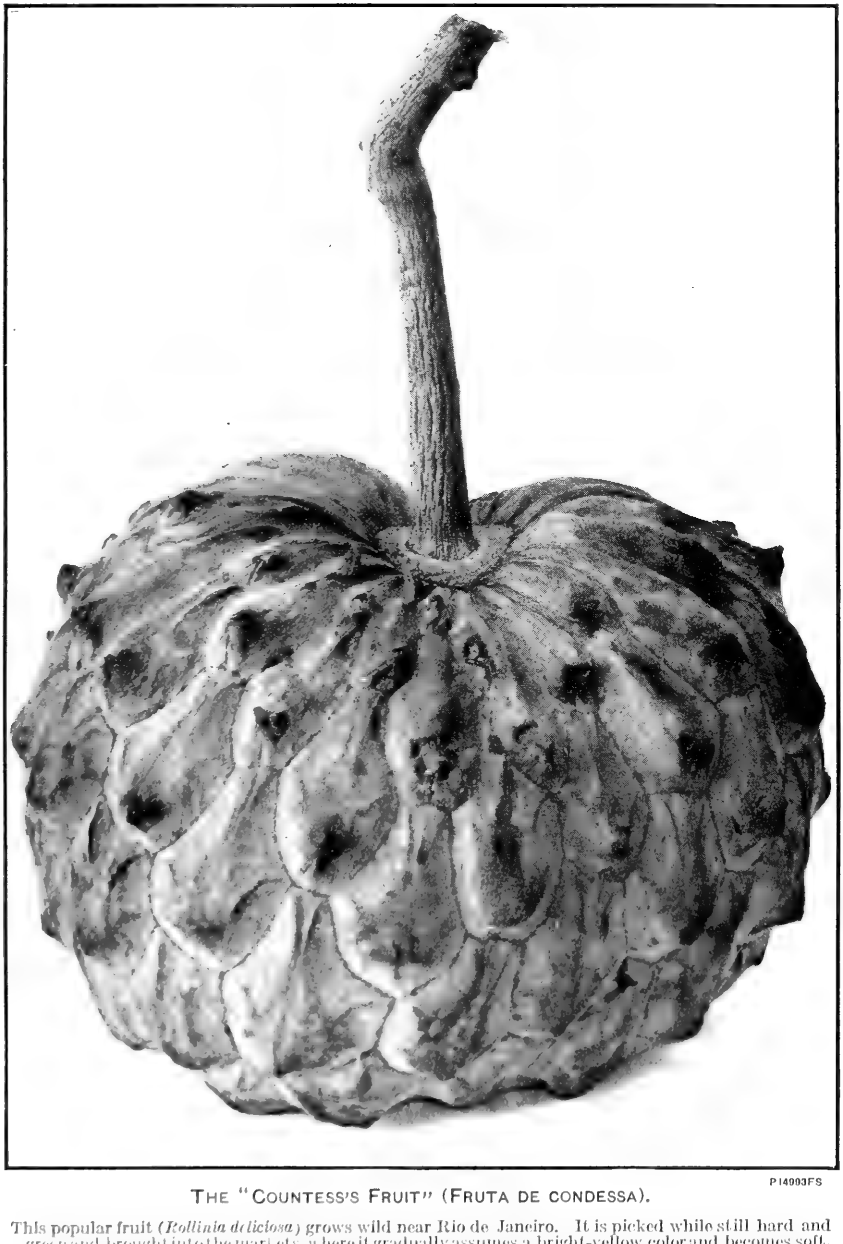
PERA DO CAMPO.

The pera do campo or cabacinha do campa (pear of the campo or gourd of the campo; botanically *Eugenia klotzschiana* Berg) is found near Lavras, Minas Geraes, and also at Sitio, about 100 miles east of Lavras; but it is extremely rare in both places and the natives themselves in many cases seem not to be familiar with it. The plants usually grow in groups or patches and are so low that it is often difficult to distinguish them among the grass. The aromatic, penetrating odor of the fruits, however, which is noticeable several yards away, frequently furnishes a clue to their location.

The plant is not bushy or shrubby in growth, but usually sends up several slender, unbranched stems 1 to 2 feet in height. When growing along the banks of ravines this habit is sometimes changed, the stems attaining a height of 4 or even 5 feet and giving rise to a few slender, drooping lateral branches. The leaves are lanceolate, 3 to 5 inches long, rather hard and brittle, silvery pubescent on the under surface. The slender pyriform fruits, 2 to 4 inches in length, ripen from November to January. In appearance they somewhat resemble pears except in their more elongated form and downy surface (Plate XIX). The thin, delicate skin is light yellow to golden brown in color. The flesh resembles that of a pear in color and texture; it is extremely juicy and possesses a strong aromatic fragrance indicative of its flavor, which is acid, spicy, and refreshing. Little is known of its uses, but it is probably better suited to culinary use than for eating fresh, because of its acidity and a possible slight purgative effect. The seeds, one to four in number, are irregularly oval in shape and occupy a comparatively small amount of space in the center of the fruit, a rather unusual thing in a wild species of Eugenia.

LIMÃO DO MATTO.

The limão do matto (lemon of the forest; *Rheedia edulis* Planch. and Triana) is a rare fruit, cultivated to a small extent at Lavras, Minas Geraes. The tree is small, upright, sometimes pyramidal in form, of handsome appearance, with its oblong, glossy, deep-green leaves 4 to 6 inches in length. The fruit (Pl. XX) is about 2 inches long, usually elliptical, tapering at both ends, and bright orange in color. The thick, tough skin incloses a mass of light-colored, juicy, aromatic pulp of rather acid flavor. The seeds vary from one to three in number and are oblong or oval in form, about an inch in length. If cut or bruised, a viscous, bright-yellow fluid exudes from them. In quality, the fruit of this species seems slightly inferior to *Rheedia brasiliensis*, which grows at Rio de Janeiro.



P14993FS

THE "COUNTESS'S FRUIT" (FRUTA DE CONDESSA).

This popular fruit (*Rollinia deliciosa*) grows wild near Rio de Janeiro. It is picked while still hard and green and brought into the markets, where it gradually assumes a bright-yellow color and becomes soft. It contains numerous dark-brown seeds about the size of an average bean, each surrounded by milky white flesh, which is sugary sweet and of good flavor. Photographed at Rio de Janeiro, Brazil, March 16, 1914. (Natural size.)

P15475FS

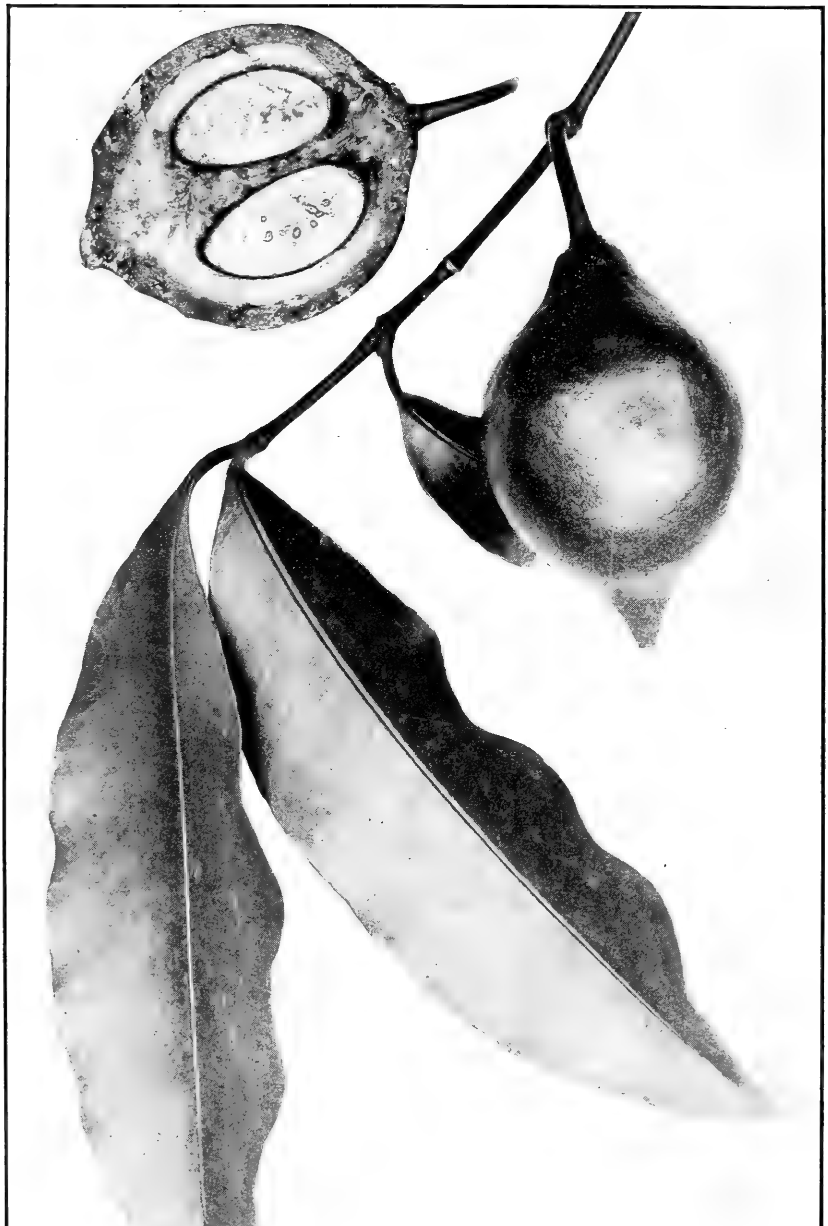
GOVERNMENT AGRICULTURAL EXPERIMENT STATION AT BARBACENA, BRAZIL.

This experimental farm is maintained in connection with the Aprendizado Agricola, a government agricultural school, the main building of which is visible on the distant hilltop. As the climate of this region is somewhat temperate, due to its 3,000 feet altitude, the cultivation of a number of Temperate Zone fruits is possible. Extensive varietal tests and acclimatization work are in progress. Photographed January 29, 1914.

P15464FS

THE PERA DO CAMPO (EUGENIA KLOTZSCHIANA), A SPICY FRUIT FROM THE CAMPOS OR ROLLING PLAINS OF SOUTHEASTERN BRAZIL.

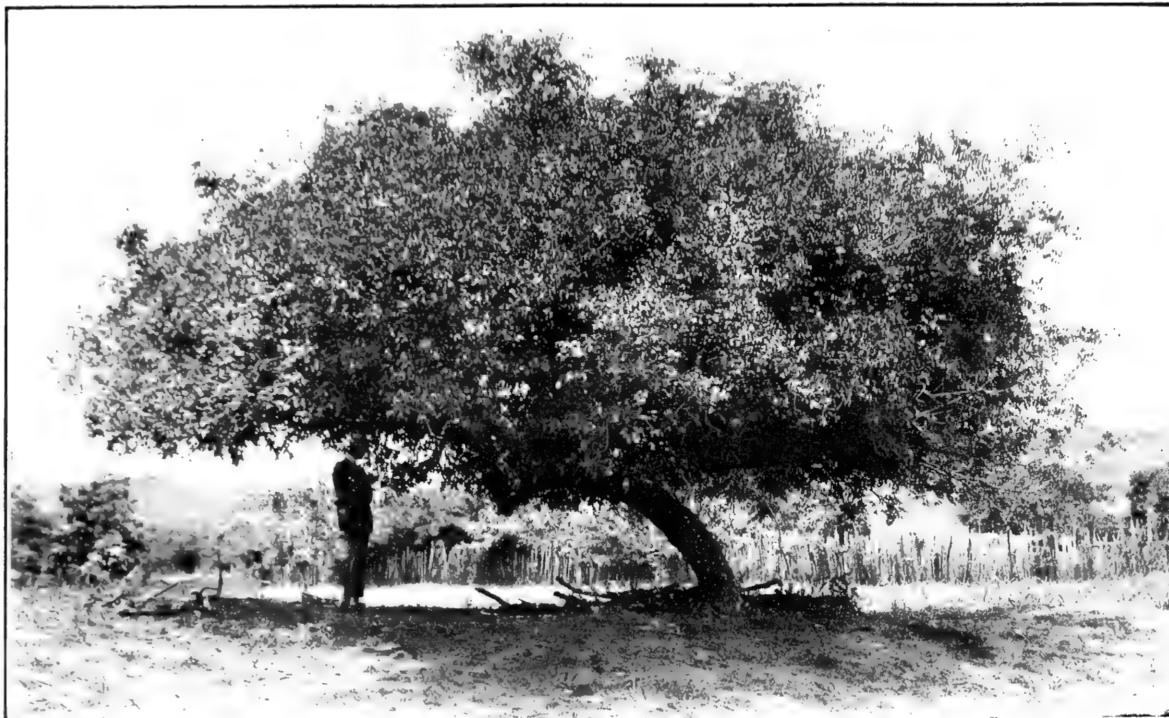
This little-known fruit is called *pera do campo* (pear of the campo) or *cabacinha do campo* (gourd of the campo). Its flesh is white, melting, very juicy, acid, spicy, and refreshing. It possesses such a pleasant aromatic fragrance that the fruit can frequently be scented on the campo before the plant is seen. The seeds are small in proportion to the size of the fruit, a rather rare occurrence in a wild Eugenia. Photographed at Sitio, Minas Geraes, Brazil, January 29, 1914. (Natural size.)



P15428FS

THE LIMÃO DO MATTO ("LEMON OF THE FOREST").

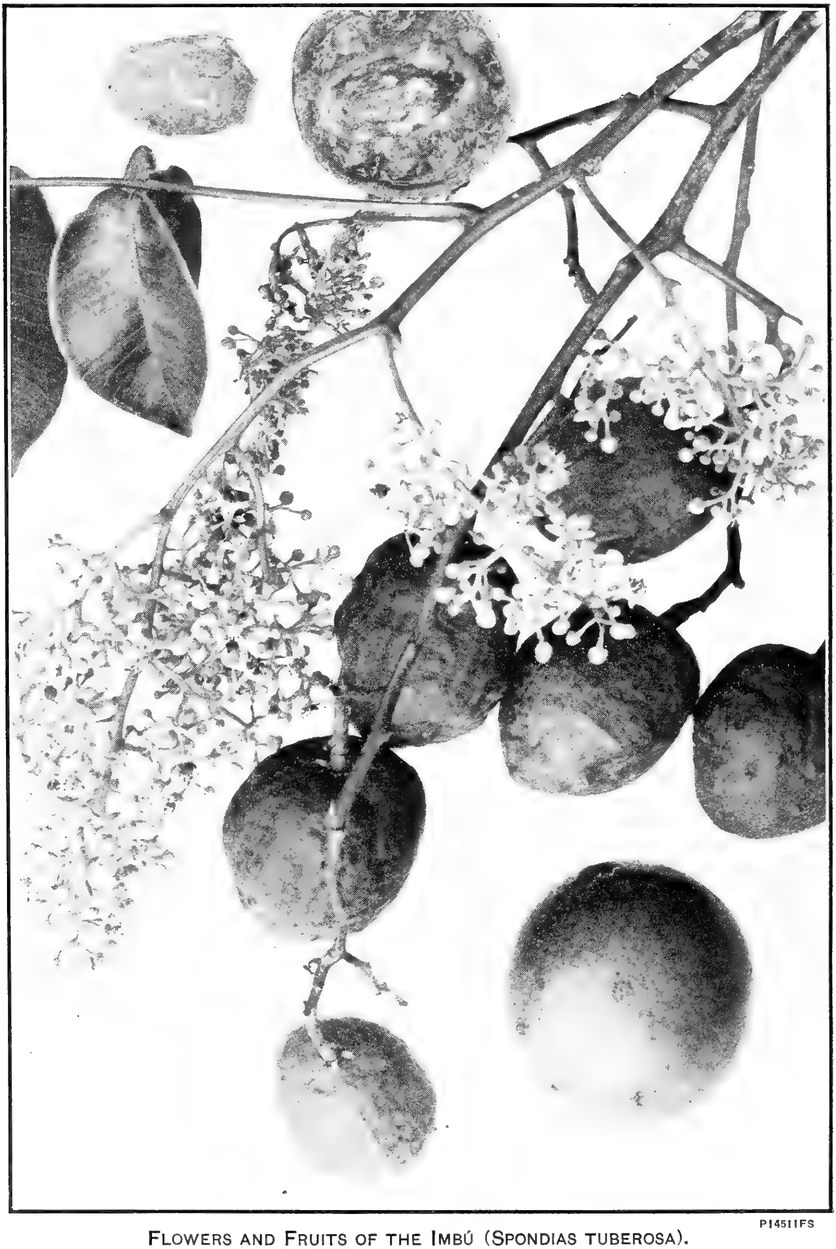
A handsome small tree (*Rheedia edulis*), with striking dark-green foliage. The attractive, medium-sized, round or oblong yellow fruit somewhat resembles a lime or small lemon. When fully ripe, the light-colored juicy pulp loses most of its acidity, has a pleasant flavor, and is slightly aromatic. The tree is related to the mangosteen. Photographed at Lavras, Minas Geraes, Brazil, January 12, 1914. (Natural size.)



P14830FS

THE IMBÚ TREE (SPONDIAS TUBEROSA).

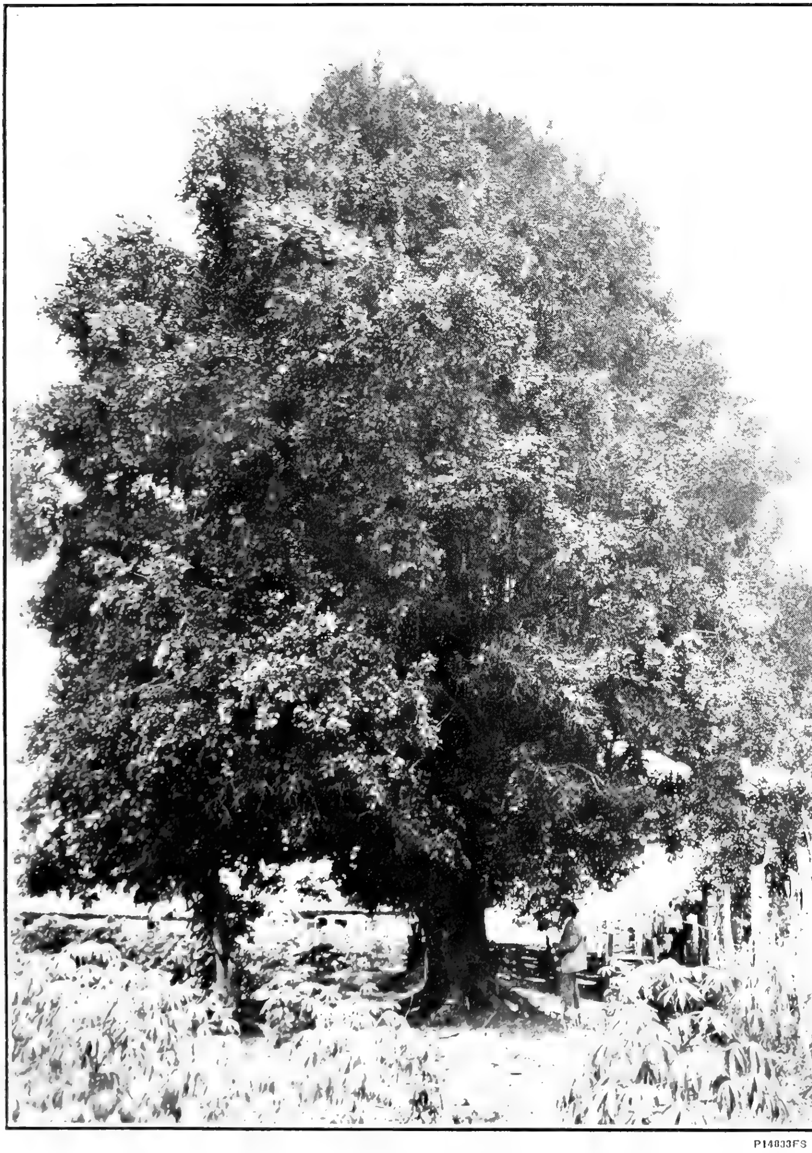
Among the native plants on the caatingas or dry lands of the State of Bahia, few are of greater importance to the people than the imbú tree, the fruit of which forms an important article in their dietary. It is not often cultivated, the wild trees apparently being sufficiently abundant to supply the inhabitants of the small interior towns with all the fruit they can consume or dispose of. Photographed at Brejo, Minas Geraes, Brazil, February 14, 1914.



P14511FS

FLOWERS AND FRUITS OF THE IMBÚ (SPONDIAS TUBEROSA).

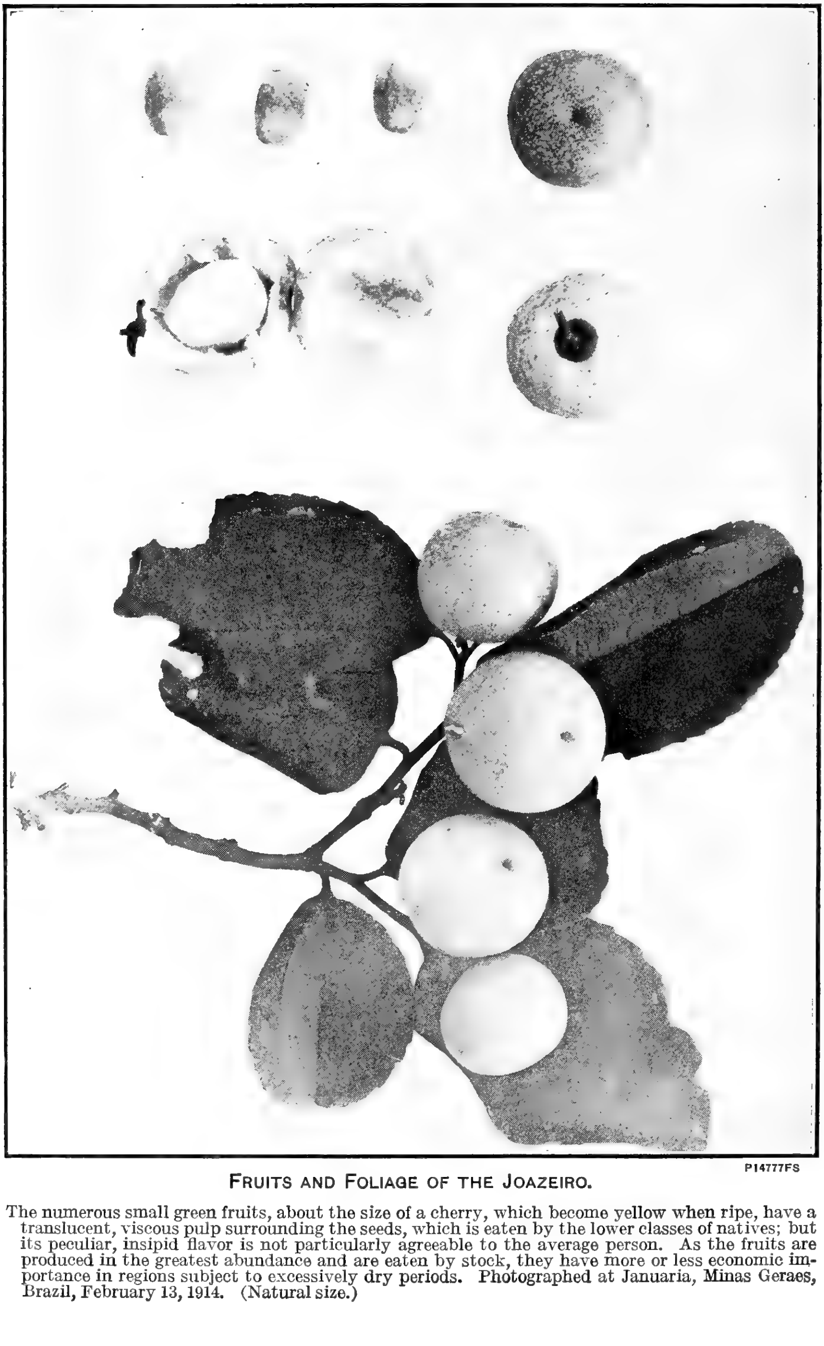
The thick yellow skin of the fruit incloses a juicy pulp of a subacid flavor, somewhat suggestive of a sweet orange. The natives, in addition to eating quantities of the fresh fruit, make imbú jelly and a famous Brazilian dish called imbuzada, prepared by mixing the juice of the imbú with boiled sweet milk, sweetened to taste. This is a delightfully pleasant and refreshing drink, not altogether unlike whipped clabber with sugar, except that it has a decidedly fruity flavor. Photographed at Bahia, Brazil, December 15, 1913. (Natural size.)



P14833FS

THE JOAZEIRO (ZIZIPHUS JOAZEIRO), AN INTERESTING DRY-LAND TREE.

This is a handsome evergreen tree, with dense green foliage and is said to be the only plant on the caatingas which retains its foliage through the long season of drought. The fruit (called *jua*) and foliage are eaten by stock. Photographed at Brejo, Minas Geraes, Brazil, February 14, 1914.



P14777FS

FRUITS AND FOLIAGE OF THE JOAZEIRO.

The numerous small green fruits, about the size of a cherry, which become yellow when ripe, have a translucent, viscous pulp surrounding the seeds, which is eaten by the lower classes of natives; but its peculiar, insipid flavor is not particularly agreeable to the average person. As the fruits are produced in the greatest abundance and are eaten by stock, they have more or less economic importance in regions subject to excessively dry periods. Photographed at Januaria, Minas Geraes, Brazil, February 13, 1914. (Natural size.)

THE SUGAR-APPLE.

In the small towns throughout the interior of Minas Geraes and Bahia States the sugar-apple (*Annona squamosa* L.) is one of the most important cultivated fruits. It is known here as pinha (pine cone; probably so called because of the similarity in appearance). Originally brought to the interior from Bahia, it is believed, the tree found such congenial surroundings and produced fruit of such excellent quality that it has gradually taken first place in many gardens. The fruit is peddled about the streets by small boys, large specimens selling for 2 vintens (less than 2 cents), smaller ones for a vintem.

In flavor the sugar-apples of this region are superior to those of the coast. They are not so large as those of Bahia, but there is a peculiar delicacy of flavor and tenderness of flesh which is lacking in the latter place. This may be due in part to the fact that the fruits are allowed to remain on the tree until fully ripe, while at Bahia they appear to be picked a trifle too soon and are then ripened in the house.

A good sugar-apple is 3 inches in diameter and usually heart shaped. Within its rough exterior is a mass of snow-white delicately flavored pulp containing numerous black seeds the size of a bean. The pulp separates into slender, conical segments, each one containing a seed. After being picked from the tree the fruit is placed in a cool place for 24 hours, when it becomes soft and ready to eat. It is always eaten while fresh, no methods of cooking or preserving it being known.

THE SWAMP ARATICUM.

Near the village of Urubu, on the Rio Sao Francisco some distance below Januaria, the low, swampy lands which extend back from the river bank a distance of three or four hundred yards are covered with *Annona spinescens* Mart., a compact, spiny shrub known to the natives as araticum do brejo, or "swamp araticum." This plant is often found on ground which is submerged under a foot or two of water during part of the year. It grows to a height of 8 or 10 feet and produces an abundance of oblong-conical fruits 2 to 3 inches in length, reddish orange in color and externally covered with small conical protuberances. When fully ripe, these fruits are so soft and delicate in texture that it is difficult to handle them without breaking the skin. The flesh is of the same color as the exterior and of a sweet, insipid flavor, apparently not relished by the natives, as they allow the hogs to consume the crop. The seeds are very numerous and do not separate easily from the pulp. The species may prove valuable, however, as a wet-land stock for the cherimoya or for breeding purposes.

THE IMBÚ.

Among the drought-resistant plants of the caatinga or semiarid section of interior Bahia, the imbú (*Spondias tuberosa* Arruda) is of particular interest. It is abundant and highly appreciated, not only in the interior of Bahia State, but also in Pernambuco and other sections of northeastern Brazil. To the natives it is a most important article of diet, taking the place of the cultivated fruits which are so common around the city of Bahia, but in the interior found only in the gardens of the better classes. During the ripening season imbús may be had for the gathering. Natives go out from every village into the surrounding caatinga, often to a distance of several miles, and bring in bushels of the fruit on their burros or diminutive ponies, consuming much of it immediately, but not forgetting to store away an abundance in the form of jam or jelly for the time to come when the imbú can not be obtained. In all the towns and villages along the Rio Sao Francisco, in Bahia State, imbús are plentiful in the markets, and the ground around the market places is often literally covered with the skins and seeds. A basket containing a quarter peck or more of the fruit can usually be purchased for 2 or 3 cents.

The imbú tree (Pl. XXI) is distinguishable from other growths on the caatinga by its low, spreading head, sometimes 30 feet in diameter. Its fruit is produced on slender stems, mainly toward the ends of the branches. Some trees are so productive that the fruit, when allowed to fall, forms a carpet of yellow upon the ground.

In general appearance the imbú (Pl. XXII) may be likened to a greengage plum. It is oval, about an inch and a half in length, slightly less in breadth, and light greenish yellow when ripe. The skin is somewhat thicker than that of a plum, with the result that it is not eaten along with the pulp. The flavor of the soft, melting, almost liquid pulp is suggestive of a sweet orange. It is frequently eaten before fully ripe and soft, when it is rather acid, though not disagreeably so. The seed, oblong and about three-fourths of an inch in length, is difficult to separate from the inner pulp which adheres to it.

The natives of the interior will often tell one that there are several varieties of the imbú, one being round, another oblong, and so on. The fact is that seedling variation results in the fruit of every tree being different from its neighbors in some minor characteristic of size, form, or flavor. No doubt the fruit could be greatly improved by selection, even in a few generations.

The imbú furnishes the basis for a dish famous throughout northeastern Brazil, known as imbuzada. This is made by adding the juice of the fruit to boiled sweet milk. The mixture is greenish white in color and when sweetened to taste is relished by nearly everyone on first trial. Imbú jelly is another well-known product, obtainable in the stores of Bahia, Rio de Janeiro, and other coastal and interior cities.

THE JOAZEIRO.

Another interesting tree of the caatingas is the joazeiro, or juazeiro (*Ziziphus joazeiro* Mart.), from which the town of Joazeiro takes its name. This tree grows along the banks of the Rio Sao Francisco in Bahia State, but is not abundant in most parts. It rarely occurs in large groves, but is usually scattered among the other plants along the river and on the caatinga. When it attains mature size it forms a beautiful, dark-green, umbrageous head 30 feet in diameter (Pl. XXIII). The leaves are hard and brittle in texture, oval to ovate, about 2 inches in length. The small wood is armed with short, stiff thorns, which are not, however, particularly dangerous.

The fruits (Pl. XXIV) vary greatly in size according to the tree by which they are produced. The largest ones are nearly an inch in diameter, round, and creamy yellow in color. Inside the thin skin is a layer of mealy flesh, within which lies the seed, surrounded by a mass of translucent, mucilaginous pulp. In size and shape the seed resembles a small olive stone. The pulp adheres to it very closely and can scarcely be separated, even in the mouth. The flavor is peculiar and somewhat insipid.

Natives of the poorer classes gather up the fruit and use it for food, but it is as a source of stock feed in dry regions that the tree seems to have its greatest value. The trees bear prodigiously, the ground under them being covered with fruits at the end of the season. These are considered fattening and reported to be readily eaten by cattle and swine. In addition, the ornamental value of the tree and its drought-resisting qualities make it worthy of note. It is said to be the only plant on the caatinga which retains its leaves during excessively dry periods.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 446

OFFICE OF THE SECRETARY
Contribution from the Office of Farm Management
W. J. Spillman, Chief

Washington, D. C. ▼ January 10, 1917

THE COST OF PRODUCING APPLES IN WENATCHEE VALLEY, WASH.

[A detailed study, made in 1914, of the current cost factors involved in the maintenance of orchards and the handling of the crop on 87 orchards.]

By G. H. Miller, *Assistant Agriculturist*, and S. M. Thomson, *Scientific Assistant.*

CONTENTS.

	Page.
Introduction	1
Summary of results	2
Description of region	2
Method of survey	6
Orchard management	10
Handling the crop	26
Material costs	33
Fixed costs	33

INTRODUCTION.

This bulletin is the first of a series designed to meet the long-standing need for a careful study of apple orcharding in various parts of the United States which would give comparative and detailed information on the different methods of orchard management in vogue and the several factors which enter into the cost of apple production. This particular study was made during the summer and fall of 1914 in Wenatchee Valley, Chelan County, Washington, in territory tributary to the towns of Wenatchee, Monitor, and Cashmere. Complete and detailed data[1] were secured on the bearing apple orchards of 87 ranches,[2] and the figures presented represent conditions as they actually existed on the farms when surveyed in 1914.

[1] Unfortunately, few farmers keep accounts which would give the necessary information for a study of the cost of conducting various farm enterprises. However, ample experience in the Office of Farm Management has shown that although farmers may not have accurate records of their work, expenditures, and income, the average farmer does have in mind fairly accurate information on these points, and this information can be obtained from him by skillful questioning when the questions are stated in the terms in which the farmer thinks. The Office of Farm Management has therefore developed the method of studying cost of production by means of the farm survey, in which information is obtained from a large number of farmers by direct interviews. In many instances it has been possible to compare averages thus obtained with accurate records, and the results justify the conclusion that when the survey method is properly and skillfully used the information obtained by it is ordinarily as accurate as the results secured in carefully conducted field experiments. The survey method was used in obtaining the information contained in this bulletin.

[2] The word "ranch" is a local term for any farm, and the word "rancher" is used in the sense of farmer.

Note.—Acknowledgment is due to the Office of Horticultural and Pomological Investigations of the Bureau of Plant Industry for material assistance in the preparation of this bulletin.

SUMMARY OF RESULTS.

The salient facts concerning these 87 orchards brought out by this investigation, made in the summer and fall of 1914, are, in brief, as follows:

The average investment per farm surveyed is $20,974; the average investment per acre of bearing apples alone is $1,925. The equipment investment is high, being $444 per ranch, or $47 per acre, exclusive of stock. There is an average of two horses per farm, or 5.3 tillable acres per horse.

The total annual cost of production is $469.73 per acre, or $0.792 per box, f. o. b. Of this, labor-cost constituted $179.09 per acre, or $0.302 per box, and cash-cost, including interest on investment, $290.64 per acre, or $0.49 per box. This is the annual cost for the average orchard under clean cultural management. Where under alfalfa or clover management, this cost is reduced about $0.02 per box.[1]

Orchards average 6½ acres and 81 trees per acre. Trees average 11 years of age.

In the Wenatchee Valley proper, counting every bearing orchard, the leading 10 varieties in order of importance are: Winesap, Jonathan, Esopus, Rome Beauty, Stayman, Gano, Ben Davis, Yellow Newtown, Arkansas (Mammoth Black Twig), and Arkansas Black. On the basis of the number of young trees, 1 to 5 years of age, inclusive, the order is Winesap, Delicious, Jonathan, Rome Beauty, Stayman, Esopus, Winter Pearmain, Banana, Gano, and Yellow Newtown.

The yield per acre on the bearing orchards from which data were secured is 593 boxes, or 7.3 boxes per tree. This represents all yields on trees from 7 to 11 years, inclusive.

DESCRIPTION OF REGION.

The State of Washington (see fig. 1) is divided by the Cascade Mountains into two unequal and distinct parts, which results in a wide variation in climate and rainfall. West of the Cascades there is an annual rainfall sufficient for the growing of crops, while east of the mountains there are sections which have an annual precipitation of less than 8 inches, necessitating irrigation. The irrigated area is relatively small compared with the upland prairies, where the rainfall is sufficient for farming without irrigation. Fruit growing in eastern

[1] No account has here been taken of the depreciation of the orchards. If it is assumed that an orchard remains in full bearing for 30 years and then is removed, the rate of depreciation is 3⅓ per cent. This per cent of $1,925, the average value per acre of the orchards surveyed, is $64.17. That is, the depreciation is $64.17 per acre, or $0.1082 per box with the average yield of 593 boxes per acre. This is probably a maximum figure. It is probable that if the facts concerning the orchard depreciation were known they would add to the cost here something between $0.04 and $0.08 per box. This assumes, of course, that the orchard is in full bearing 30 years.

Washington is mainly confined to the irrigated sections. Naturally, with such a wide variation in climatic conditions, different areas have developed distinct types of farming.

The principal apple-producing areas of the State lie in the counties of Yakima, Chelan, Spokane, Kittitas, Walla Walla, and Asotin. There are extensive plantings of young trees in the county of Okanogan, while considerable acreage of apples is found in the counties of Douglas, Grant, Benton, and Klickitat. The most important in the production of apples, according to output, are the counties of Yakima, Chelan, and Spokane.

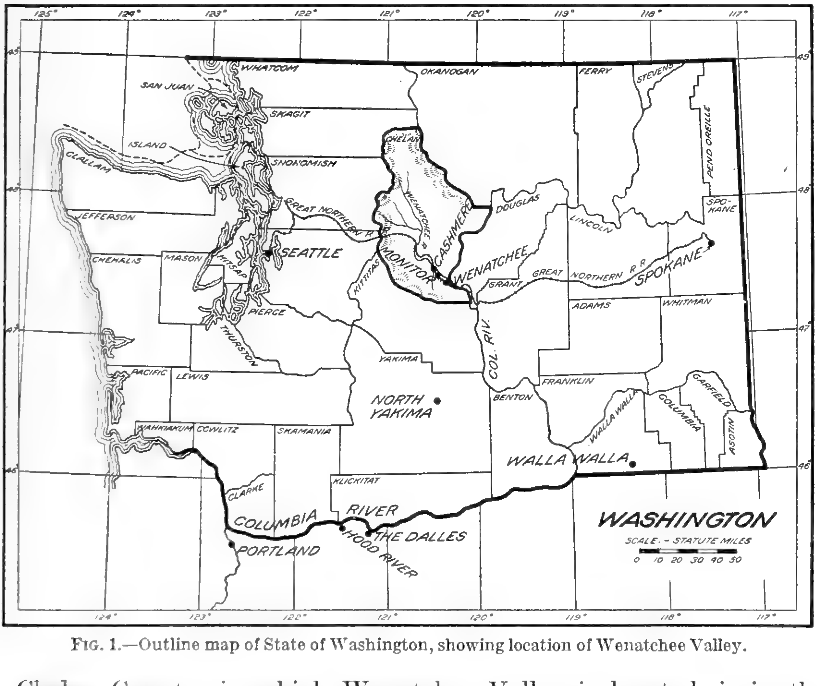


FIG. 1.—Outline map of State of Washington, showing location of Wenatchee Valley.

Chelan County, in which Wenatchee Valley is located, is in the north central portion of the State, having one of the main ranges of the Cascade Mountains on its western and northern boundaries, while the Columbia River flows on its eastern boundary, receiving the waters from several mountain streams which have their source in the Cascades. The principal apple-producing area lies in Wenatchee Valley in the vicinity of the towns of Wenatchee, Monitor, and Cashmere, and extends as far up the valley as Leavenworth. (See Pls. I, II, and III.) A very intensive region is in the semicircular area about the town of Wenatchee, which extends to the west for about 1½ to 2 miles with a gradual increase in elevation of from 700 feet at the railroad station to 850 where the foothills are approached, and to the north until it meets the Wenatchee River about a mile from its entrance into the Columbia. From here the orchard area extends northwest along the narrow valley and adjacent slopes of the Wenatchee River to the town of Cashmere, a distance of about 12 miles. There is considerable variation of altitude throughout the valley, but most of the fruit is grown in an area from 700 to 1,000 feet in elevation.

Records were taken only in the vicinity of Wenatchee, Olds, Monitor, and Cashmere, and all data here presented refer only to orchard management in those sections, unless otherwise stated. Whenever Wenatchee Valley, or "the valley," is referred to in this bulletin, it has specific reference to the region in the vicinity of the above-mentioned towns. However, orchards are similarly managed throughout the remainder of the valley.

CLIMATE.

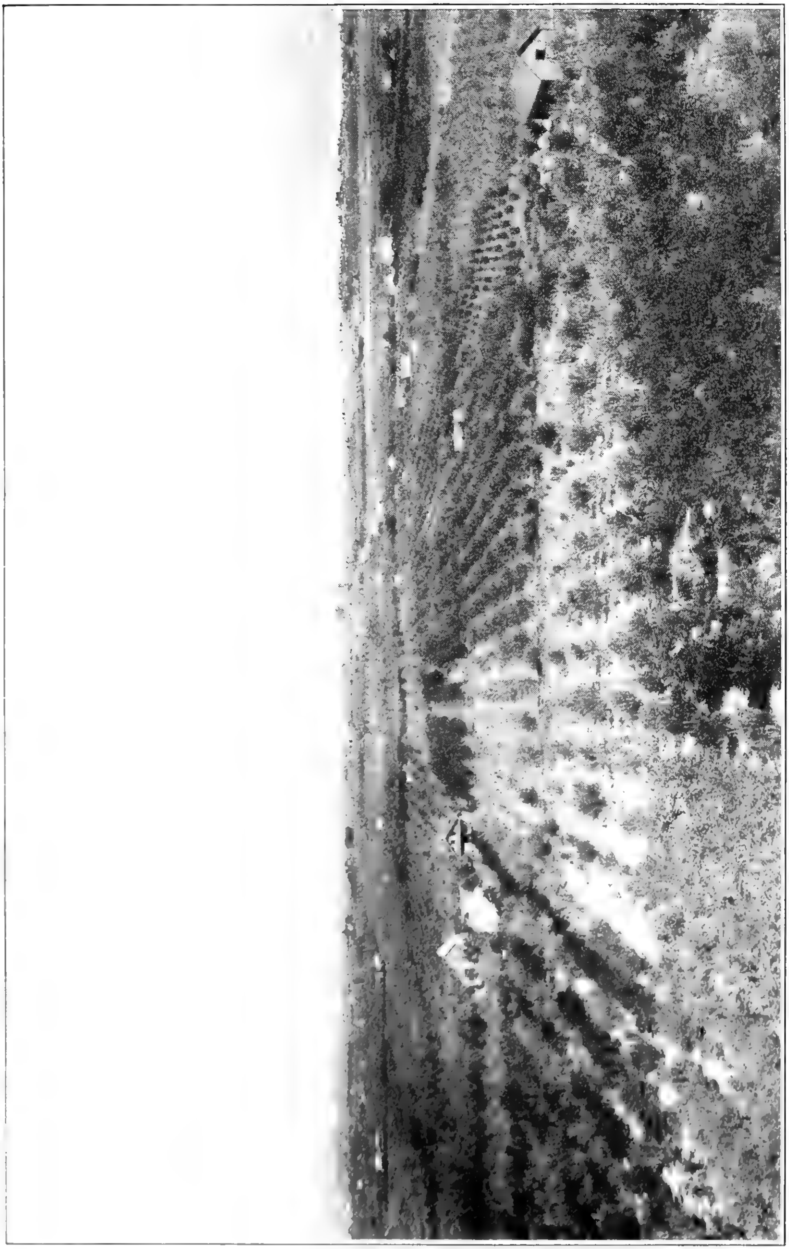
The climate of the valley is decidedly arid and no crops are grown without irrigation. The temperature during the summer is often high, but not oppressive. There is considerable variation in the altitude and the annual precipitation. The orchards lie for the most part between the altitudes of 700 and 900 feet. There is in the valley an annual precipitation from 8 to 15 inches. Killing frosts are not common during the growing season. Generally speaking, Wenatchee Valley has a pleasant and delightful climate that is very favorable to the growing fruit.

SOIL.

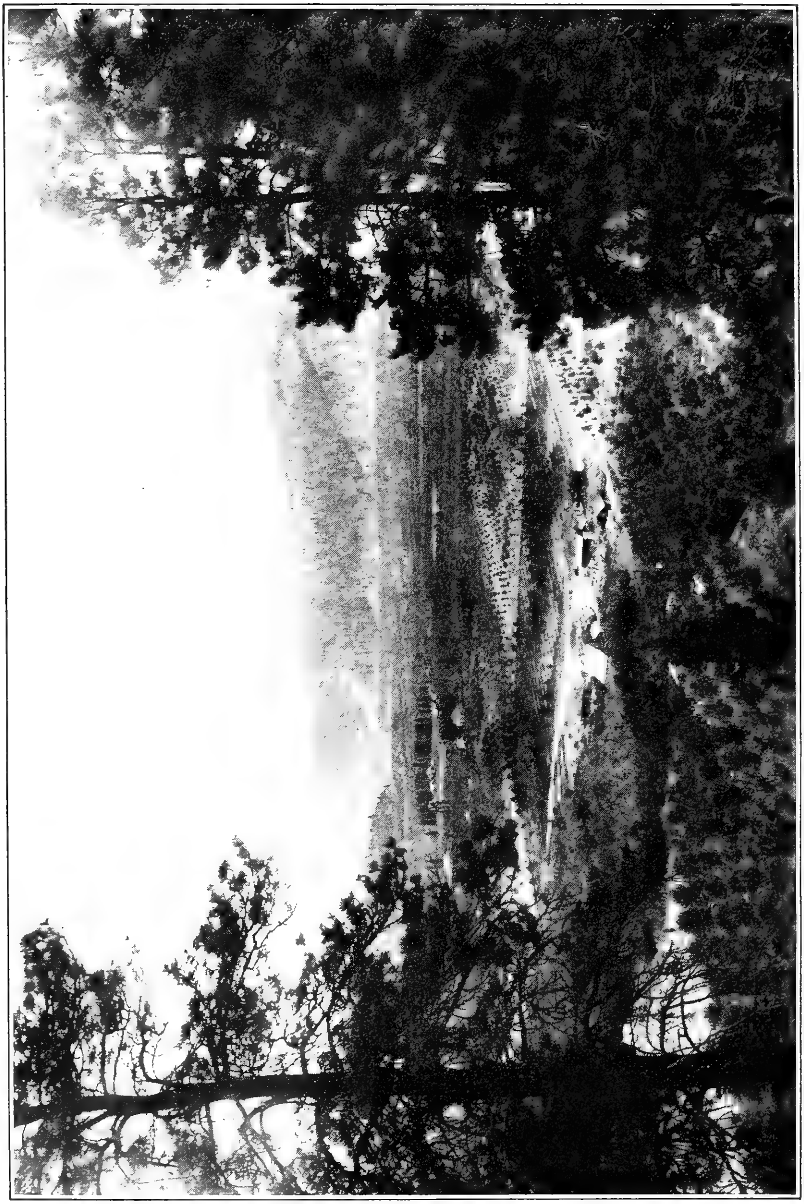
The soils of the Wenatchee Valley are loamy, varying from "a very fine silty loam through coarser grades to sandy loam." The subsoil is of sand and gravel and the bedrock sandstone and shale.[1]

[1] As far as origin is concerned, the soils of the Wenatchee Valley are mainly of two types, namely, the broad alluvial fans which are located at the foot of the steeper slopes and which appear to the best advantage in the sweeping semicircle which contains the town of Wenatchee with the neighboring orchards. At the mouths of each of the several canyons these fans have been formed. The canyons have been carved mainly in the upturned sandstones and clays which come originally from the granite rocks. Above the town of Wenatchee, continuing up the valley, while there are occasional fans the river terraces are much more conspicuous. The terraces are composed at the base of glacial bowlders and gravels. Upon these one will find river gravels and sands. The soil to a depth of several feet, which has been superimposed upon the gravel and sand, is largely of eolian origin and hence is of a very fine grain and retains the moisture very readily.

In general, one might say that throughout the Wenatchee Valley the bedrock is represented by upturned layers of sandstones and shales of lacustrine origin. Next comes a subsoil which is very coarse at the base, but grading upward into gravels and sands of river origin. The top soil, varying from a few inches to a hundred feet, is of very fine grain and in the main has been carried to its present position by the persistent winds which come out of the mountains to the westward. The soil is loamy in character and varies from a fine silty loam through coarser grades to a sandy loam. Rarely is it composed mainly of sand, but in general it has the right physical properties to retain the moisture with readiness. Chemically, it is good in lime, iron, and potash, but is low in nitrogen. Cover crops which will yield nitrates have very greatly increased the yield of soil and such crops have come to be absolutely necessary in the older orchards.—HENRY LANDES, State geologist, Washington.

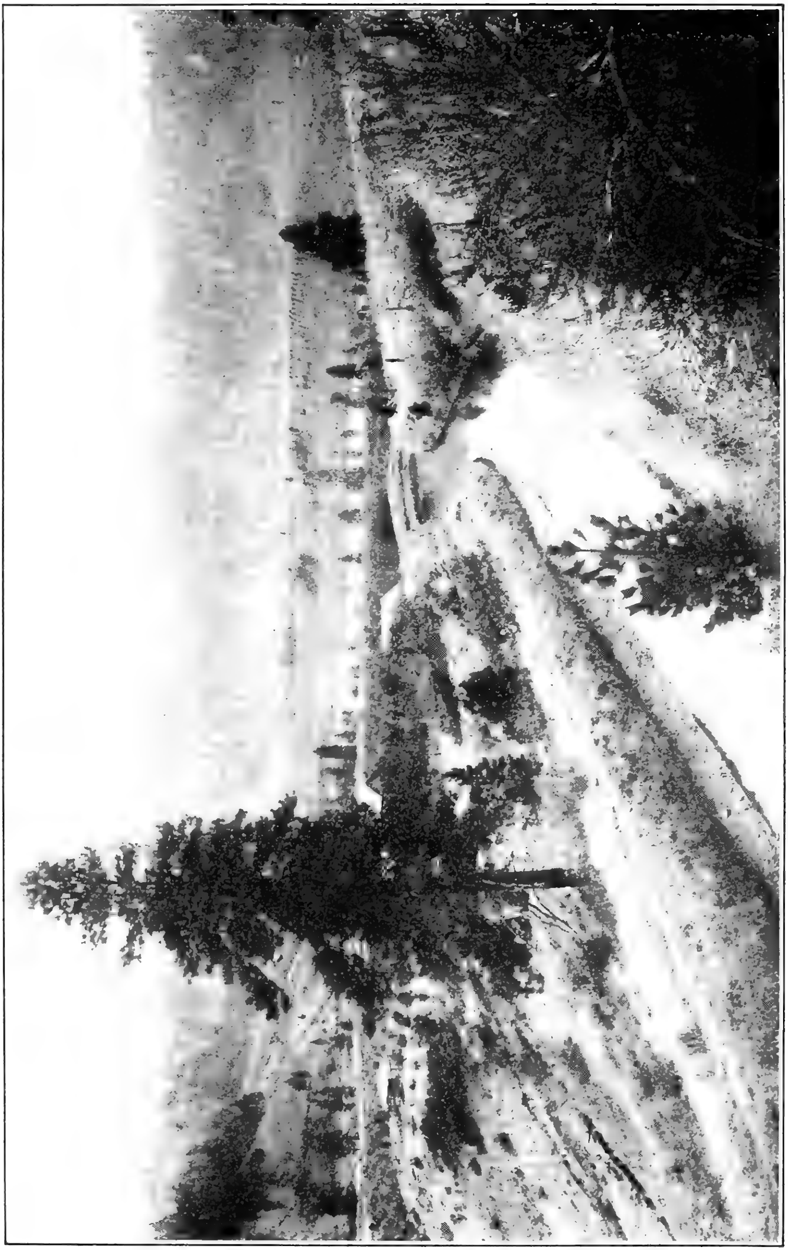


GENERAL VIEW OF THE MOST INTENSIVE APPLE-PRODUCING REGION OF THE WENATCHEE VALLEY, NOT FAR FROM WENATCHEE. CONFLUENCE OF WENATCHEE AND COLUMBIA RIVERS IN THE DISTANCE.



VIEW OF THE MOST INTENSIVE APPLE-PRODUCING AREA IN THE VICINITY OF CASHMERE.

VIEW LOOKING WEST ACROSS THE WENATCHEE RIVER, SHOWING APPLE ORCHARDS ON THE RIVER FLATS AND ON THE SLOPE NEAR MONITOR.



VIEW OF THE HIGHLINE IRRIGATION CANAL ABOVE CASHMERE, ON THE EAST SIDE OF WENATCHEE VALLEY.

AGRICULTURE OF THE REGION.

Wenatchee Valley has a highly specialized type of agriculture. It is a region of intensive fruit growing, confined very largely to the apple. The ranches, in general, are small, those included in this investigation averaging 11.4 acres in size, of which 10.5 acres are tillable. Of the tillable land, 6.5 acres were in bearing apples, 0.72 acre in other fruits, and 0.58 acre in other crops. However, there are a few large ranches devoted to fruit growing, some of them embracing several hundred acres each. The region is not adapted to an extensive type of agriculture. The two predominant limiting factors are the high price of land and the small area of irrigable land. Considerable alfalfa is grown in the valley, but it is largely grown in young orchards, and at present much of it is being grown in the bearing orchards. The soil and climate are adapted to a great variety of crops, but appear especially adapted to fruit.

DEVELOPMENT OF THE FRUIT INDUSTRY.

The first settlement in the valley was made in 1863 at Cashmere, then named Mission, by Father Grassi, who later diverted the waters of Mission Creek to water a small garden near the mission.

The first fruit trees were set out by the Miller brothers, some reports giving the date as 1873, others 1876. The first irrigation ditch in the valley was established by the same men in 1883, and still exists as the Miller ditch.

Practically the entire Wenatchee Valley was a barren waste until 1896, when the Gunn ditch was built, covering 600 acres of irrigable land. During the same year the North Wenatchee Canal Co. was formed and the ditch built covering the Warner Flat near Cashmere. This ditch was taken over by the Highline in 1902, and now forms a part of the latter system.

In 1901 W. T. Clark, of North Yakima, was interested in the prospects of developing the irrigation system in the Wenatchee Valley and soon thereafter took over the organization of the Highline (Wenatchee Highline Canal Co.). The ditch as built covered 9,000 acres of orchard land and was completed to Wenatchee in October, 1903. (See Pl. IV.) This was the real beginning of the orchard development in the Wenatchee Valley. Development continued until in 1913 there were more than 20,000 acres of irrigable land under the different ditches.

The planting of fruit trees was more or less correlated with the development of irrigation. Table I gives the total apple acreage in north central Washington and the acreage in the Wenatchee Valley.

TABLE I.—*Total apple acreage and number of trees in north central Washington and in Wenatchee Valley.*[1]

North central Washington:	
Total apple acreage	41, 711
Total number of apple trees	2, 678, 172
Number of apple trees, 10 years and over	227, 695
Wenatchee Valley:	
Total apple acreage	11, 445
Total number of apple trees	736, 455
Number of apple trees, 10 years and over	164, 927

The growth and importance of the apple industry in north central Washington is also shown by the increase in the number of cars of apples shipped during the 10 years 1905–1914 (Table II).

TABLE II.—*Number of cars of apples shipped from north central Washington from 1905 to 1914, inclusive.*

Direction of shipments.	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Cars east	254	222	508	995	492	1,851	1,201	3,413	3,546	5,913
Cars west	257	202	150	274	118	343	507	887	910	980

METHOD OF SURVEY.

In making a study of this kind it is highly important that average conditions of the district be obtained. At the beginning of this particular investigation many orchardists in the intensive commercial apple-producing regions about Wenatchee, Olds, Monitor, and Cashmere were visited. In choosing the ranches from which records were obtained no effort was made to select the seemingly better class of orchardists. In order to make the data uniformly comparable, it was imperative that the orchards chosen should contain trees of the same bearing age; that the trees should be uniform and typical of the region; that the orchard should contain only apple trees and not be interset with peaches, pears, plums, or other fruit trees; that intertillable crops other than cover crops should not be present; that the orchard should be managed as the representative commercial apple orchard of the valley; that if the trees were top-worked such trees should have been worked over to the present variety for at least five producing seasons, and that the manager, renter, or person doing the work should have had supervision of the orchard for at least five years so as to be conversant and thoroughly acquainted with the methods of management, conditions, and yields of the orchard for such a period.

Where conditions did not conform to these limitations, as a rule data were not taken. Where any discrepancy arose after data had

[1] The north central Washington tree census for 1915—State department of agriculture.

been taken, the records were not used in the final compilations. After eliminating the discrepancies there were 87 complete records which fully met the specifications.

INVESTMENTS.

Estimates of the amount of capital invested were obtained from each orchardist. This estimated value, in the majority of cases, was the amount the rancher paid for the place, plus the value of such improvements as he had made since the purchase. There were a few ranchers who had owned their property before local land values had advanced to any great extent. Most of these men based their estimates on prices that at some time or other had been offered for their holdings. These estimates were generally found to approximate closely prices that had been paid for adjacent land in bona fide sales. The values may seem high, but they represent actually what the majority of men visited in this investigation either had paid or had been offered for their orchards. In all probability a lower valuation would be given now (1916).

As figured from the estimates of the 87 owners, the average total investment per ranch is $20,974, while the average investment in bearing apple orchards per ranch is $12,250. By giving each of the 87 orchards the same weight, that is, taking the estimated value of a single acre of bearing apples as representative of each orchard, there is an estimated average investment of $1,925 per acre for bearing apples. The annual interest charge on this alone amounts to $154 per acre, at 8 per cent. (See Table III.)

TABLE III.—*Average investment and average acreage per ranch (87 ranches) in Wenatchee Valley in 1914.*

Average investment per ranch	$20,974.00
Average investment per acre	$2,026.00
Average size of ranch (acres)	11.4
Average size of bearing apple orchard (acres)	6.5
Average value per acre of bearing apple orchard	$1,925.00

COMMERCIAL VARIETIES GROWN.

Over 60 varieties of apples are grown in Wenatchee Valley. In some of the older orchards are found the Baldwin, Rhode Island Greening, Northern Spy, Ben Davis, York Imperial, and other varieties which are of little commercial importance to the orchardists of the valley. These varieties were planted by the earlier pioneers.

The older commercial orchards of the valley to-day contain for the most part varieties such as Winesap, Jonathan, Esopus, and Rome Beauty. The Winesap, Jonathan, Stayman, Rome Beauty, together with the Delicious, have been planted to a considerable extent within the last five years. Table IV gives the first 10 varieties, 10 years or over, in order of their importance, and the first 10 varieties between 1 and 5 years of age in order of their importance, according to the number of trees planted.

The trees in the valley were originally planted on the square, diamond, or quincunx plan. The distances set varied from 20 by 20 feet to 28 by 28 feet. The majority were set from 20 to 22 feet apart on these various systems.

TABLE IV.—*Varieties of apples in order of number of trees planted.* (*Wenatchee Valley.*[1])

Trees 10 years of age or over.		Trees between 1 and 5 years of age.	
Variety.	Number.	Variety.	Number.
1. Winesap	28,188	1. Winesap	193,940
2. Jonathan	25,142	2. Delicious	39,597
3. Esopus	17,106	3. Jonathan	25,131
4. Rome Beauty	15,852	4. Rome Beauty	21,126
5. Stayman	13,868	5. Stayman	19,491
6. Black Ben	9,896	6. Esopus	9,851
7. Ben Davis	7,633	7. Winter Pearmain	4,030
8. Yellow Newtown	7,533	8. Banana	3,408
9. Black Twig	5,606	9. Black Ben	1,939
10. Arkansas Black	5,600	10. Yellow Newtown	1,226

[1] North central Washington tree census for 1915. Trees planted in the vicinity of Wenatchee, Olds, Monitor, and Cashmere.

AGE AT WHICH APPLE TREES BEGIN TO BEAR.

Apple trees in Wenatchee Valley begin to bear fruit at an early age. A number of estimates were obtained relative to the age that different varieties would bear a box of marketable apples per tree. There was some variation, owing to the many factors which were considered. It was, however, not difficult to obtain this information, for many orchardists had grown their trees or had come into possession of them prior to the time they began to bear. There is a considerable difference of opinion as to the exact order in which the different varieties should be placed, but most orchardists agree that the majority of the important commercial varieties under average conditions in Wenatchee Valley will bear a box of marketable apples per tree prior to 7 years of age. Table V gives the order, determined as nearly as possible, in which they come into bearing.

TABLE V.—*Ages within which commercial varieties may be expected to bear a box or more of marketable apples.*

5 to 7 years:
1. King David.
2. Missouri.
3. Jonathan.
4. Grimes.
5. Banana.
6. Stayman.
7. Winesap.

5 to 7 years—Continued.
8. Winter Pearmain.
9. Rome Beauty.
10. Black Ben.
11. Ben Davis.
12. Delicious.
13. Arkansas.

7 to 8 years:
14. Esopus.
15. Yellow Newtown.
16. Arkansas Black.

YIELDS.

Estimates of yields were obtained for a period approximating five years. In presenting data of this sort it is highly important that the yield should be considered over as long a period as possible in order to obtain a fair average for a district. Where very few orchards are over 11 years of age, as was the case in the valley at the time of this study, it is impossible to obtain a sufficient number of comparable yields for any period other than that represented by trees from 7 to 11 years of age, inclusive. The average estimate of all yields from orchards between these ages was obtained and considered as a fair average yield for the valley. In computing this average, each age is given the same weight, regardless of the year in which a given orchard might be a certain age. For example, yields on orchards at the time they were 7, 8, 9, 10, and 11 years were averaged and this average was used as the average yield for the valley. In this way 271 estimates were considered. Forty-seven were from orchards 7 years of age; 60 from orchards 8 years of age; 67, 9 years of age; 59, 10 years of age; and 38, 11 years of age. These estimates extended over a period of 6 years; 8 of them in 1909, 34 in 1910, 61 in 1911, 71 in 1912, 75 in 1913, and 22 in 1914. Considering the factors stated above, the average yield per acre of apple orchards in Wenatchee Valley with 81 trees per acre was 593 packed boxes.

There is a tendency in some apple-producing regions toward alternate bearing, and many times frosts, winds, insect pests, and diseases have an effect on the annual yield of the district, but by taking yields over a period of years on trees which are representative of a district it is possible to obtain an average yield which is accurate enough to furnish a basis for such a study as is here presented.

There is no appreciable difference in yield between clean cultivated and alfalfa orchards, nor could this be expected, since so few orchardists had followed the cover-crop management for any considerable period.

There is considerable difference in yield between different varieties, and no doubt there is a difference in the number of boxes of extra fancy, fancy, and choice grades which are packed from an acre of the different varieties. But no account was taken of this, for it was the purpose of the investigation merely to arrive at the average annual cost of producing apples, grown in well-managed commercial apple orchards of the valley.

LABOR.

The average size fruit ranch in the Wenatchee district is such that most of the labor, except at harvest time, may be done by the ranchers or by members of their families. But little outside labor is hired. Labor when employed by the month is paid from $35 to $50, varying with the privileges which are given. The following rates were paid labor for various operations:

Pruning	$3.00 to $3.50 per day.
Packers	.06 per box.
Packing and sorting	.07 per box.
Thinning	2.50 per day.
Man, team, and sprayer	1.50 per hour.
Picking	2.50 per day.
Man and team	5.50 per day.

Expert pruners receive from $3 to $3.50 per day, but as the majority of ranchers did this work themselves and were not considered as expert labor in the same sense as a man who makes a business of contract pruning, the pruning labor was figured at the regular rate of $0.25 per hour.

The rate of $1.50 per hour for sprayer, man, and team is high, but that was the rate paid by many of the growers who hired their spraying. This did not include the material used.

ITEMS CONSIDERED IN COST OF PRODUCTION.

In considering in detail the cost of producing apples on the farms studied the following classification of costs will be observed in this discussion:[1]

Maintenance costs:
- Manuring.
- Cultivation.
- Pruning.
- Brush handling.
- Irrigation.
- Thinning.
- Propping.
- Spraying.
- Cover crop.
- Miscellaneous labor.

Handling costs:
- Hauling box shooks.
- Making boxes.
- Hauling empties to and from orchard.
- Hauling full boxes.
- Foreman charge.
- Picking.
- Sorting, packing.
- Nailing and stamping.
- Labeling.

Material costs:
- Box shook.
- Nails.
- Paper.
- Label.
- Lime-sulphur.
- Lead-arsenate.
- Manure.
- Gasoline and oil.

Fixed costs:
- Taxes.
- Water tax.
- Insurance.
- Interest on investment.
- Equipment charge.
- Packing-house charge.

ORCHARD MANAGEMENT.

In the early days of orchard planting it was the object of the orchardist to obtain a vigorous annual tree growth. The soil at that time contained enough plant food to give the desired results, with the aid of sufficient irrigation water. The most intensive methods of cultivation were followed; scarcely a weed was allowed to remain in the orchards. This practice continued until the trees had borne a few crops, when it became apparent that more humus-forming material was necessary if the growth and productiveness of the orchards were to be maintained.

[1] No account is here taken of association or other handling charges such as storage and insurance. The total costs represent all charges up to and including delivery at an association or shipping point.

This condition led to the introduction of alfalfa, clover, and vetch as a shade or mulch crop, until to-day there are nearly 4,000 acres in alfalfa, 500 acres in clover, and 500 acres in vetch in the orchards of north central Washington. Obviously, with the introduction of these crops the method of cultural management gradually changed. At the time of this investigation this change was being made, but the new method had not been in vogue long enough, when records were secured, for the most reliable results. Nevertheless the subject of the management of such orchards is discussed briefly so as to show a comparison of the different methods and the possibility of decreasing the cost of production of the apple where the yields remain the same. There are factors which may tend to show the impracticability of

FIG. 2.—A 5-year-old Jonathan orchard near Wenatchee in which clean cultivation has always been practiced.

introducing a mulch crop, but at present it seems that yields can be kept normal by a resort to this expedient, and that at the same time the amount of labor involved in the care of the orchard can be decreased.

However, this bulletin deals primarily with the cost of producing apples in the bearing orchards studied where clean cultivation is practiced.

CLEAN CULTIVATION.

It is the common practice in all irrigated regions to begin the seasonal preparation of the soil by plowing or disking in the fall or spring. It is the purpose of these operations to put the soil in a condition to facilitate the use of the spring-tooth and the spike-tooth harrow, the cultivator, and the float. It is usually possible to begin the cultural work on the soil before the middle of April. (See fig. 2.)

Of the 57 ranchers who practiced clean cultivation, 28 began the seasonal preparation of the soil by the use of the plow, 25 by the disk harrow, 3 by the cultivator, and 1 by the spike-tooth harrow. Of the 28 who plowed, 15 did so in the fall and 13 in the spring. Not all of these orchardists, however, plow every year. Nineteen plow every year, 8 every two years, and 1 every three years.

Following the plowing or disking, cultivations are given previous to the first irrigation. All orchardists who follow any method of clean cultivation do some cultivating previous to the first irrigation. Following these first cultivations, which are usually between April 1 and May 15, the orchard is furrowed preparatory to the first irrigation. Furrowing is locally known as "creasing." Cultivations are usually given after irrigations until the middle of the summer, or until the weight of the fruit bears the limbs down so that further cultivation is impracticable. If at any time there is a rain heavy enough to pack the soil, a cultivation is usually given. Not all orchardists, however, cultivate after each irrigation. (See Table VI.)

TABLE VI.—*Analysis of operations in clean cultivation.*

Operation.	Orchardists who perform each operation.		Man.		Horse.
	Number.	Per cent of total.	Hours per acre.	Per cent of total time.	Hours per acre.
Plowing	28	49.12	2.91		5.35
Cultivation:					
Total			21.36	100.00	38.98
Before first irrigation	57	100.00	11.96	55.99	22.26
Following first irrigation	52	91.23	4.69	21.96	8.57
Following second irrigation	36	63.16	3.25	15.22	5.58
Following third irrigation	18	31.58	1.28	5.99	2.30
Following fourth irrigation	3	3.51	.13	.61	.18
Following fifth irrigation	1	1.76	.05	.23	.09
Creasing:					
Total			4.24		6.48
Before first irrigation			1.51		2.34
Before second irrigation			1.39		2.14
Before third irrigation			.93		1.34
Before fourth irrigation			.35		.55
Before fifth irrigation			.04		.06
Before sixth irrigation			.02		.05

There appears to be no particular sequence in the use of the cultural implements. The exact method by which desirable conditions of tilth are secured is in part dependent upon the local soil and climate and in part upon the individual conception of the orchardist. There enters here, however, the proper study of the soil with which each grower has to deal, the behavior of the trees, and the condition of the fruit. Early plowing and maintenance of a good soil mulch are of great advantage in retaining the moisture in the soil during the growing season. (See Table VII.)

TABLE VII.—*Number of times various implements are used in the 57 clean-cultivated orchards.*

When used.	Plow.	Disk harrow.	Spring-tooth harrow.	Spike-tooth harrow.	Culti-vator.	Float.
Previous to first irrigation	28	39	66	42	25	22
Following first irrigation		2	36	14	24	8
Following second irrigation			24	12	14	5
Following third irrigation			11	5	6	2
Following fourth irrigation			1			
Following fifth irrigation			1			

There are many factors which may affect the time required for the various operations. Among these are number in crew, time of year, topography, type and condition of soil, kind of cover crop, if any, depth to which implements are worked, and kind and size of implement used. (See Table VIII.)

TABLE VIII.—*Average time required and cost per acre for various cultural operations on farms studied in Wenatchee Valley.*

Implement.	Width of implement.	Number of—		Acres per 10 hours.	Cost per acre.
		Men.	Horses.		
Plow	12 inches	1	2	1.49	$3.679
Disk harrow	5 feet	1	2	4.46	1.232
Spring-tooth harrow	6 feet	1	2	5.90	.932
Spike-tooth harrow	7 feet	1	2	9.60	.572
Cultivator		1	2	6.30	.873
Float	10 to 14 feet	1	2	7.50	.733

Considering all records, regardless of number in crew, or kind or size of implement used, a total of 21.36 man-hours and 38.98 horse-hours per acre was chargeable for all cultivation, exclusive of plowing and creasing, or a per acre cost of $11.19. Considering all cultural operations, including plowing and creasing, there was a total charge of $14.75 per acre.

MANURING.

In the early days of orchard planting throughout the valley, the trees made a luxuriant growth, and at the time that they came into bearing gave a good crop, which did not seem to affect the physical condition of the tree the year following. It was the impression that this virgin soil contained an abundance of plant food, so that the need of returning fertility to the soil was not felt. Later, however, this valley gained some valuable lessons from the experience of other northwestern sections, and many orchardists began to apply manure. Inasmuch as the average ranch throughout the valley is small, the grower usually having only one or two horses and in some instances a cow, not enough manure is produced to make a thorough application each year to the entire orchard.

Of the 87 ranchers from whom records were taken, 49, or 56 per cent of the total number, applied each year the little manure produced on the place. This amounted to about 4 tons per acre, which was usually applied directly from the wagon by one man with two horses, covering 1.44 acres in 10 hours. This is not efficient work as compared with results on farms where large quantities of manure are handled annually. This inefficiency may be due in part to difficulty of spreading manure in orchards planted very closely together, but it can be more generally attributed to the fact that the manure is not applied during a rush season, hence the grower takes his time. Where all records are considered, regardless of crew or method of handling, there is an average labor cost for applying manure of $2.27 per acre.

PRUNING.

Pruning is an annual practice of all orchardists in the valley. It is usually done during the dormant condition of the tree, in the late fall or early spring. However, some men practice summer pruning; if so, it is generally done as a supplement to winter pruning.

There are many factors that influence the number of trees that may be pruned in 10 hours. The more important of these are the age of the tree, the variety and habit of growth, the height and shape of the tree, the distance apart, the efficiency and skill of the pruner, the previous method of pruning, and the amount of work to be done.

Considering the average number of trees per acre as 81 and 19.3 trees as the average number of trees pruned per 10-hour day, there will be an annual charge of 40.31 man-hours per acre, or a cost of $10.08.

HAULING BRUSH.

In connection with the annual pruning of the orchard, the disposition of the brush takes more or less time. This operation is usually done either by two men and two horses or by one man and two horses. (See Table IX.)

The brush is often gathered in the center of the tree rows at the time of pruning or after pruning. This makes it much easier to handle the brush quickly. As a general rule, however, a crew of two men and two horses with a wagon will pass between the tree rows, the men gathering the brush on either side of the wagon, and hauling it to some convenient place and burning it, either at once or later in the season when the brush has dried. The trees are so young and the pruning generally has been so well done that there is a very small amount of large wood, so that practically very little trimming up of the pruned wood is necessary.

Considering the number of man-hours and horse-hours required for this operation, and assuming that the amount of brush was the same in each instance, it appears from Table IX that the most economical way to remove brush is by the 2-men and 1-horse crew. However, as there are only five records of this method, this result can not be taken as conclusive.

TABLE IX.—*Average number of acres of brush removed by different crews in 10 hours.*

Number of records.	Number of—		Acres per 10 hours.	Cost per acre.
	Men.	Horses.		
43	2	2	1.56	$5.12
25	1	2	.93	5.90
9	1	1	.90	4.43
5	2	1	1.50	4.34

Considering all records, there is an annual charge of 11.86 man-hours and 14.46 horse-hours per acre for handling the brush, at a cost of $5.14 per acre.

FURROWING.

Furrowing, or "creasing," is a practice of making small ditches for distributing water for irrigation. The cultivator and the shovel plow are the implements most commonly used for this operation. In clean cultivation furrows are made just prior to the time of irrigation. All orchardists furrowed once; 91 per cent, twice; 63 per cent, three times; 31½ per cent, four times; and 3½ per cent, five times. Most alfalfa orchardists furrowed but once, just after the spring cultivation. A few of the alfalfa orchardists made a practice of cleaning out the furrows following the harvesting of alfalfa.

Usually a 6-foot cultivator with three shovels attached, one at either end and one in the middle, is used for making furrows. Four to six furrows, varying in depth from 4 to 6 inches, and approximately 3 feet apart, are usually made between tree rows.

A crew of one man and two horses with the 6-foot cultivator, making the usual number of furrows—six between rows—covered 8.3 acres per day, at a labor cost of 66.3 cents per acre. A crew of one man and one horse with the shovel plow, making the usual number of furrows—five between rows—covered 5.15 acres per day, at a labor cost of 77.6 cents per acre. (See Table X.)

TABLE X.—*Average time and cost of making furrows in clean-cultivated orchards with the 6-foot cultivator or the shovel plow.*

Implement.	Number of—		Acres per 10 hours.	Man-hours per acre.	Horse-hours per acre.	Cost per acre.
	Men.	Horses.				
6-foot cultivator	1	2	8.3	1.204	2.408	$0.663
Shovel plow	1	1	5.15	1.94	1.94	.776

In making furrows in alfalfa orchards the shovel plow is most frequently used. For the 30 records under consideration, 19 used the shovel plow, 11 with 1 horse and 7 with 2 horses; 8 used the cultivator, and 3 used miscellaneous tools. A crew of 1 man and 1 horse, using the shovel plow, making the usual number of furrows—five between rows—covered 5.02 acres per day, at a cost of 79.7 cents per acre; while a crew of 1 man and 2 horses with the shovel plow averaged 4.9 acres in 10 hours, at a cost of $1.12 per acre. Where the 6-foot cultivator was used, 7.57 acres, on an average, were covered per day at a cost of 72.7 cents per acre. (See Table XI.)

TABLE XI.—*Average time and cost of making furrows in cover-crop orchards with the 6-foot cultivator or the shovel plow.*

Implement.	Number of—		Acres per 10 hours.	Man-hours per acre.	Horse-hours per acre.	Cost per acre.
	Men.	Horses.				
6-foot cultivator	1	2	7.57	1.32	2.64	$0.727
Shovel plow	1	1	5.02	1.99	1.99	.797
Do	1	2	4.90	2.06	4.12	1.120

IRRIGATION.

In the Wenatchee Valley the supply of water for irrigation purposes is obtained principally from the Wenatchee River and its tributaries. It is distributed at altitudes a little above the location of the orchards through several irrigation ditches, thence to the orchards through laterals. These laterals may be open ditches, wooden flumes, or pipes. The water is delivered from the laterals to the farm. At the point of delivery on the farm, the water received is distributed either into earth head ditches, small wooden flumes, or pipes, and from these it is distributed by means of furrows throughout the orchard. Along the earth head ditches small wooden spouts are placed at intervals to regulate the flow of water into the furrows. The wooden flumes receiving the water from the laterals are usually about 6 to 8 inches in width at the bottom, having sides 6 to 8 inches in height, with auger holes at regular intervals through which the water passes into furrows. Small metal slides or pieces of lath are placed over the auger holes for the purpose of regulating the amount of water passing into the furrows. Where the water is piped into the orchard, there are usually placed at points opposite each tree row small standpipes with garden valves, which deliver the water directly into the furrows.

In regions where the supply of water is limited, the furrow system seems to be the most satisfactory means of distributing the water. This is practically the universal method for irrigating orchards throughout the Northwest.

The operation of turning the water on the land is termed a "set." It may be necessary if the head of water is small to make several changes or "sets" before the entire area is irrigated. This is usually the case, especially where the orchard tracts are large. For this reason the orchardist turns the whole of the head into a few furrows and allows it to run from 12 to 72 hours, varying with the type and condition of the soil. The water is allowed to run until, by a slow lateral movement, it has thoroughly saturated the soil between the furrows. As a rule the rancher judges merely by the surface conditions of the soil as to when sufficient saturation has taken place. When he finds that the area has become well saturated, he turns the water into another portion of the orchard, and so on until the entire area is irrigated.

Many factors affect the time and labor of irrigation. The principal ones are: Water head; contour of land; method of delivery, whether open ditch, flume, pipe, or faucet; number, length, and depth of furrows; kind of soil; physical condition of soil; cultural method; atmospheric conditions; gophers.

On the average, four irrigations are made in Wenatchee Valley annually. The first irrigation is usually made between the 1st and 15th of May, the second between the 1st and 15th of June, the third between the 1st and 15th of July, and the fourth between the 1st and 15th of August. In some instances irrigations are made as early as April and as late as the middle or latter part of September. There are a few orchardists who make as many as nine irrigations.

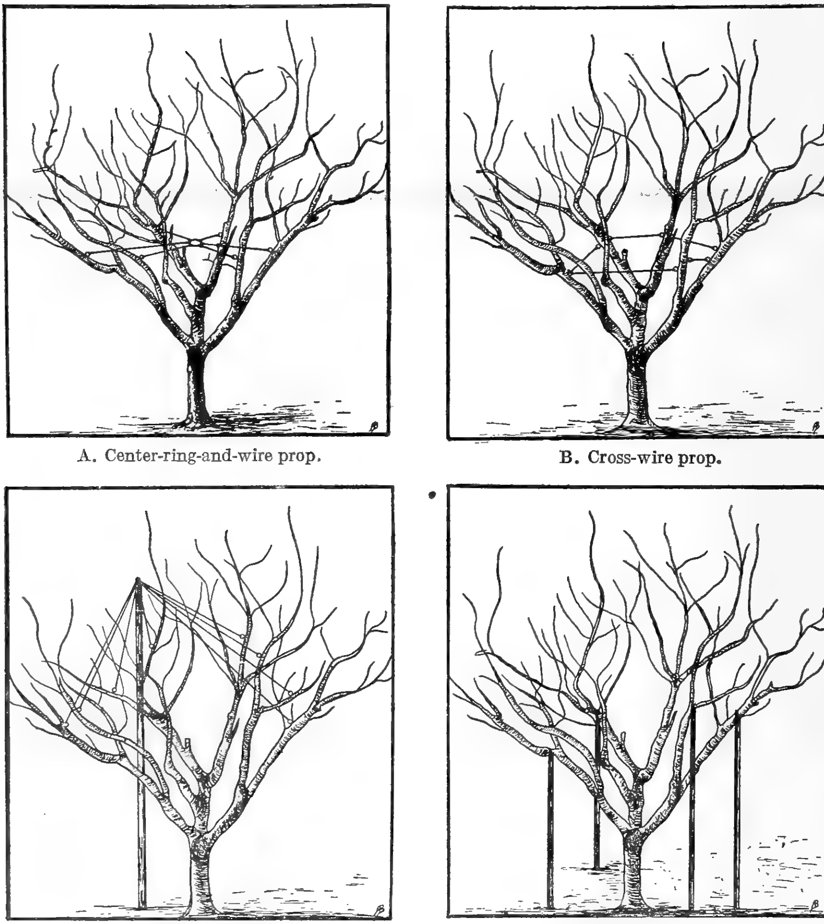
There is practically no difference in the time required for irrigating the alfalfa and the clean cultivated orchards. On those farms studied in the valley, the average number of man-hours per season necessary to irrigate an acre of clean-cultivated orchard was 34.37, making a labor cost of $8.59, while the average time necessary to irrigate 1 acre of an orchard in alfalfa was 35.66 man-hours, making a labor cost of $8.92.

THINNING.

Practically every orchardist in the valley thins his fruit. Thinning is very important, and the quality of the fruit which matures depends to a great extent upon the amount of thinning done. There are some varieties which require more thinning than others. The Missouri, Wagener, Grimes, Yellow Newtown, and King David are varieties which perhaps demand more thinning than any others in order to produce a fruit of marketable size. This thinning is generally done after what is known as the "June drop," when the apples begin to approach the size of a walnut. Many times it is impossible to get all the thinning done at this time, other operations interfering.

Many men thin two or three times during the season. The size and age of the tree have considerable bearing on the length of time required for this operation.

There are two methods of thinning used in the valley, with shears and by hand. The length of time required for each of these methods is affected not only by the efficiency and experience of the operator



A. Center-ring-and-wire prop. B. Cross-wire prop.

C. Center-pole-and-wire prop. D. Single-pole prop.

FIG. 3.—Four methods of propping apple trees in Wenatchee Valley. The single-pole prop is most commonly used.

but by the density of the foliage and the equipment which it may be necessary to use on account of the size of the tree.

In some seasons it is of course necessary to thin more heavily than in other seasons. When a large crop is expected heavy pruning is done the winter before, and in that way some of the work of thinning is obviated. Under normal conditions the trees of the valley usually bear a heavy crop every other year.

The factors which appreciably affect the time required for thinning may be summed up as number of trees per acre, variety, size of tree, age, method of pruning adopted, water supply, soil condition, method of thinning (by shears or by hand), density of foliage, equipment, hail, tendency to alternate bearing, and the quantity of fruit removed. Considering all records, the average time per acre required for this operation was 53.29 man-hours at a cost of $13.32.

PROPPING.

The regularity of the apple crop in the valley necessitates the practice of propping annually. This is done any time throughout the growing season when the weight of the fruit bears the limbs down so

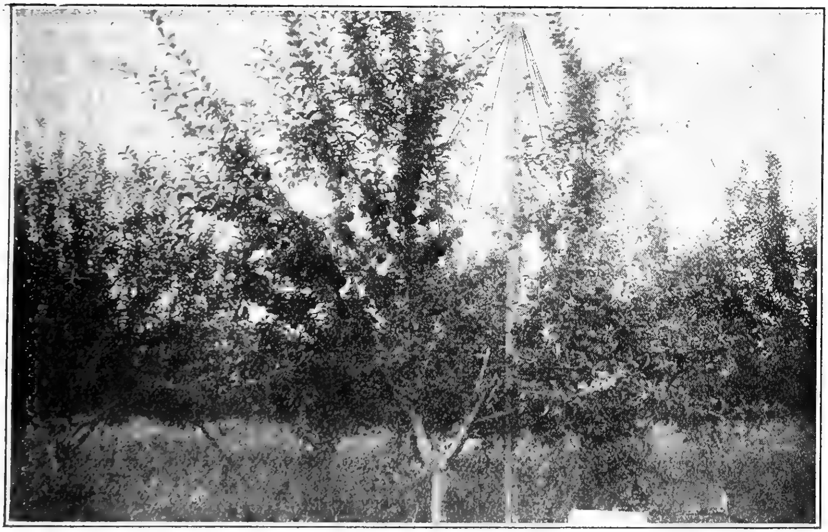


FIG. 4.—The center-pole-and-wire method of propping. This tree is a 3-year Winesap graft on a 5-year-old Wagener stock.

that there is danger of their breaking. Four methods of propping are used by the orchardists: The center-ring-and-wire, the cross-wire, the center-pole-and-wire, and the single-pole prop.

In the center-ring-and-wire method (A, fig. 3) screw eyes are placed in the main limbs at some distance above the crotch of the tree. Wires are attached to the screw eyes and brought to a ring placed approximately in the center of the tree. This holds the tree in shape and prevents the breaking of the limbs at the time when the crop is on.

In the cross-wire method (B, fig. 3) screw eyes are placed in the main limbs at some distance above the crotch. From each screw eye a wire extends and is attached to a limb opposite or nearly so. This answers the same purpose as the former method.

In the center-pole-and-wire method (C, fig. 3) screw eyes are placed in the main limbs, to which are attached long strands of wire. At the end of each strand is a loop which is placed over a nail driven in the end of a pole. This pole is raised to a position nearly parallel to the trunk of the tree and set. This draws the wires tight, holds the tree in shape, and prevents the limbs from breaking. (See also fig. 4.)

The single-pole prop method (D, fig. 3) is most common. This single pole usually consists of a 1 by 2 inch or 1 by 4 inch pine strip varying in length as conditions demand. The 8 to 12 foot lengths are most commonly used. These props are usually sharpened at one end so as to make it easy to place them in the ground. The end which is to hold the limb is V-notched or small lath strips are tacked on each side of the prop, practically forming a notch.

There are three methods of single-pole propping in common use. First, one crew may haul and scatter the props through the orchard while another crew sets them up (A, Table XII); second, a crew may haul the props out and set them as they go (B, Table XII); third, the props may be hauled out and set up as needed (C, Table XII). Sometimes an orchardist may carry out and set them as needed.

The time required for this operation is no doubt more variable than that for any other operation.

TABLE XII.—*Average time per acre required on farms studied for propping with the single-pole prop used in three ways.*

Operations.	Number of—		Acres per 10 hours.	Per acre.		
	Men.	Horses.		Man-hours.	Horse-hours.	Cost.
Method A:						
Hauling to orchard	1	2	4.56	2.19	4.38	$1.205
Setting up	1		.596	16.81		4.203
Hauling from orchard	1	2	4.60	2.17	4.34	1.194
Total				21.17	8.72	6.602
Method B:						
Hauling to orchard	1	1	5.58	1.79	1.79	.716
Setting up	1		.694	14.40		3.60
Hauling from orchard	1	1	5.58	1.79	1.79	.716
Total				17.98	3.58	5.032
Method C:						
Hauling out and propping	1	2	.878	11.39	22.78	6.265
Hauling from orchard	1	2	4.42	2.45	4.90	1.348
Total				13.84	27.68	7.613

All records considered, there is an acre charge of $6.36 for propping.

SPRAYING.

All orchardists in the valley spray annually, realizing the vital importance of a thorough and systematic application of spray materials to insure the production of marketable apples.[1]

[1] Since the investigation, other diseases and insects have caused some change in the spray calendar in the Wenatchee Valley.

The spray outfit usually consists of a $2\frac{1}{2}$ to $3\frac{1}{2}$ horsepower gasoline engine and a 150 to 250 gallon tank mounted on a truck. Two 50-foot lengths of spraying hose, with 8 to 10 foot bamboo extensions and nozzle attachments, complete the outfit. A single nozzle is most commonly used with each hose. Only a few of the outfits carry a spray tower. Not every orchardist owns an outfit. Some own a share in an outfit, while others hire their spraying done. When the spraying is hired, a man with team and sprayer receives $1.50 per hour, the orchardist furnishing the material.

The first application of spray is made when the trees are dormant, the second when 75 to 90 per cent of the petals have fallen, the third two to three weeks following the second, and the fourth during the latter part of August or the first of September.

The first, or "dormant," spray is made with a lime-sulphur solution, during a period of calm weather soon after the snow disappears from the ground. Commercial lime-sulphur is usually used for the "dormant" spray with a 1 to 10 solution; i. e., 1 part of lime-sulphur to 9 parts of water. It is usually made from March 10 to April 10; the greater part of the work, however, is done from March 20 to April 10, at which time the leaf buds are beginning to burst. A coarse spray is applied with Bordeaux nozzles, a pressure of 150 to 175 pounds being maintained. Some orchardists do not make the winter lime-sulphur spray each year. Of the records considered, 81 made this an annual practice, while 6 used this spray every other year. A crew of 3 men and 2 horses is most commonly used, although there were a few 1-man and 2-horse, 2-men and 1-horse, and 2-men and 2-horse crews. A crew of 3 men and 2 horses will spray 3.51 acres in 10 hours, applying 6.1 gallons per tree, or 491.1 gallons per acre. (See Tables XIII, XIV, XV, XVI, and XVII.)

TABLE XIII.—*Acres sprayed in 10 hours and amount of material applied per tree by a 3-man and 2-horse crew.*

Item.	Material.			
	Lime-sulphur.	First lead-arsenate.	Second lead-arsenate.	Third lead-arsenate.
Acres per 10 hours	3.51	3.35	3.59	3.64
Gallons per tree	6.1	6.7	6.2	5.9

The first codling-moth, or lead-arsenate, spray is applied when 75 to 90 per cent of the petals have fallen. All orchardists make this spray. A fine spray is used and a pressure of from 180 to 250 pounds is maintained. It is the purpose to force this spray well into the calyx for future protection of the apple against the work of the codling-moth larva. A crew of 3 men and 2 horses will spray 3.35 acres in 10 hours, applying 6.7 gallons per tree, or 539 gallons per acre.

The second codling-moth spray is usually applied from May 20 to June 1. The Bordeaux or Vermorel nozzles are used with a fine spray, and a pressure of from 150 to 175 pounds is maintained. It is the purpose of this spray to cover the small apples with material for protection against the first brood of codling-moth larva, which begins to appear at this time. A crew of 3 men and 2 horses will spray on the average 3.59 acres in 10 hours, applying 6.2 gallons per tree, or 505 gallons per acre.

The third codling-moth spray is usually applied from July 20 to July 31. The Bordeaux or the Vermorel nozzle is used with a fine spray, and a pressure of from 150 to 175 pounds is maintained. It is the purpose of this spray to cover the apples with material for protection against the codling-moth larva. The second brood of larva is usually hatching at this time. A crew of 3 men and 2 horses will spray 3.64 acres in 10 hours, applying 5.9 gallons per tree, or 478 gallons per acre.

TABLE XIV.—*Labor and material costs per acre for spraying where a crew of 3 men and 2 horses is used.*

Kind of spray.	Number of growers.	Per acre.			Gallons.			Material cost per acre.
		Man-hours.	Horse-hours.	Labor cost.	Per day.	Per acre.	Per tree.	
Lime-sulphur[1]	69	8.79	5.86	$3.08	1,734	494	6.1	$8.89
First lead-arsenate[2]	76	8.95	5.97	3.13	1,804	539	6.7	2.15
Second lead-arsenate	55	8.34	5.56	2.92	1,812	505	6.2	2.02
Third lead-arsenate	44	8.24	5.49	2.88	1,740	478	5.9	1.91
Fourth lead-arsenate	3	9.66	6.44	3.38	1,743	561	6.9	2.24

1 Lime-sulphur, strength 1 to 10.
2 Lead-arsenate, strength 2 pounds to 50 gallons of water.

There are a few orchardists who make a fourth lead-arsenate spray the latter part of August or the first of September.

Lead-arsenate is used with a strength of $1\frac{1}{2}$ to 2 pounds of material to 50 gallons of water in all codling-moth sprays.

Of the 85 records considered in spraying, 84 made the "dormant" lime-sulphur spray; 22 made only the first codling-moth spray; 22 made only the first and second codling-moth sprays; 37 made the first, second, and third codling-moth sprays; 4 made the first, second, third, and fourth codling-moth sprays. In all sprays considered, there was an average of 81 trees per acre, with an average age of 11.5 years.

TABLE XV.—*Labor costs per acre for spraying, all records, regardless of crew used.*

Kind of spray.	Number of growers.	Number making spray.	Cost.		
			Per acre.	Per tree.	Per box.
Lime-sulphur	85	84	$2.84		
First lead-arsenate	85	85	3.07		
Second lead-arsenate	85	63	2.12		
Third lead-arsenate	85	50	1.68		
Fourth lead-arsenate	85	4	.15		
Cost when all sprays are used			9.86	$0.1217	$0.0166

Numerous factors influence the cost of spraying. The variety and size of trees and their distance apart, the character and the contour of the land on which the spraying is done, the convenience of facilities, the purpose of the spray, condition and kind of material used, the thoroughness of the work, and whether the trees are dormant, partly or wholly in foliage, all have their bearing on the time required for the spraying operation. The average cost for spraying where all records are considered is $13.15 per acre for material and $9.86 for labor, or a total of $23.01 per acre. (See Tables XVI and XVII.)

TABLE XVI.—*Material costs per acre for spraying, all records.*

Kind of spray.	Number of ranchers.	Number making spray.	Gallons material per acre.	Cost.		
				Per acre.	Per tree.	Per box.
Lime-sulphur	85	84	467	$8.41		
First lead-arsenate	85	85	523	2.09		
Second lead-arsenate	85	63	362	1.45		
Third lead-arsenate	85	50	275	1.10		
Fourth lead-arsenate	85	4	25	.10		
Cost when all sprays are used				13.15	$0.1623	$0.0222

TABLE XVII.—*Total cost per acre of labor and materials for spraying all orchards.*

Kind of spray.	Number of growers spraying.	Total cost.	Cost per acre.		Total cost per tree.	Total cost per box.
			Labor.	Material.		
Lime-sulphur	84	$11.25	$2.84	$8.41		
First lead-arsenate	85	5.16	3.07	2.09		
Second lead-arsenate	63	3.57	2.12	1.45		
Third lead-arsenate	50	2.78	1.68	1.10		
Fourth lead-arsenate	4	.25	.15	.10		
Average cost for spraying		23.01	9.86	13.15	$0.284	$0.0388

MISCELLANEOUS LABOR.

There are many items of labor which in themselves do not appear to amount to a great deal, but in the aggregate take considerable time and make a cost which is recognized by many ranchers. Allowing these smaller needs or demands of the ranch to go unheeded for too long a period may later mean much expense of labor and money.

The principal items considered under this head are painting wounds where large limbs are removed from the trees, removing water sprouts, cleaning irrigation lateral ditches, and hoeing around the trees. These, together with a few others, make a miscellaneous labor charge per acre of 9.06 man-hours, or a cost of $2.27. (Table XVIII.)

TABLE XVIII.—*Labor and cost chargeable per acre prior to harvest on orchards under clean cultural management (57 ranches).*

Operation.	Hours per acre.		Cost per acre.			Cost per box.
	Man.	Horse.	Man.	Horse.	Total.	
Cultivation	28.52	50.82	$7.13	$7.62	$14.75	
Irrigation	34.37		8.59		8.59	
Manuring	4.32	7.92	1.08	1.19	2.27	
Pruning	40.31		10.08		10.08	
Hauling brush	11.86	14.46	2.97	2.17	5.14	
Propping	19.01	10.73	4.75	1.61	6.36	
Thinning	53.29		13.32		13.32	
Spraying (lime-sulphur)	8.13	5.42	2.03	.81	2.84	
Spraying (lead-arsenate)	19.99	13.45	5.00	2.02	7.02	
Miscellaneous	9.06		2.27		2.27	
Total	228.86	102.30	57.22	15.42	72.64	$0.1225

MULCH CROPS.

At the time these studies were made there was an increasing tendency to put down the orchards to alfalfa or some other legume. An indication of the cost of operation on 30 ranches under this management is given here.

Most alfalfa orchardists begin the cultural work on their orchards by a thorough use of the disk harrow as early in the spring as soil conditions permit. It is the purpose of this disking to split and spread the crowns of the plants, thus causing them to stool and send out new plants. The spike-tooth or the spring-tooth harrow and the float are used following the disk harrow, to fine and level the soil, making it more fit for plant growth and bringing it into shape for irrigation. Following this cultivation, furrows, or creases, are made for irrigation with a shovel plow or 6-foot cultivator. A few of the men plowed the alfalfa under once in three or four years and then reseeded it, but this is the exception. (See Table XIX.)

TABLE XIX.—*Man and horse hours chargeable per acre for cultivation in alfalfa orchards.*

Number of records.	Plowing.		Disking.		Cultivating.		Furrowing.		Total.	
	Man.	Horse.	Man.	Horse.	Man.	Horse.	Man.	Horse.	Man.	Horse.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
30	1.03	2.06	5.65	10.86	2.97	5.16	2.09	3.39	11.74	21.47

Many times, in order to facilitate irrigation, it is necessary to do other labor in the orchard, such as hand hoeing and locating the work of gophers. Such items were taken into account under miscellaneous labor. Five irrigations, on an average, were made in alfalfa orchards. Alfalfa orchards required more water than the clean-cultivated orchards; nevertheless, the average time per acre for labor connected with irrigation was not much more than in the clean-cultivated orchards.

Twenty of the orchards under alfalfa management were mown, on an average, twice. (See Table XX.)

TABLE XX.—*Man and horse hours chargeable per acre for harvesting alfalfa.*

Number of records.	Mowing.		Rake and pile.		Hauling in.		Total.		Yield per acre.
	Man.	Horse.	Man.	Horse.	Man.	Horse.	Man.	Horse.	
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
20	6.62	3.13	4.64	0.96	5.38	5.58	16.64	9.67	1.01

The figures secured indicate a cost of $11.77 per acre for cultivation and harvesting of the alfalfa crop. The total cost per acre for cultivation in orchards under clean-cultivation management was $14.75, giving a difference of $2.98 in favor of the orchards under alfalfa management. There is, however, in alfalfa orchards a cost of $8.92 per acre for irrigation, or $0.33 more than the average cost per acre for the same under clean-culture management, which would, therefore, make the difference of only $2.65 in favor of the latter. But considering the yield of 1 ton per acre of alfalfa valued at $9 per ton, there would appear to be a total difference of $11.65 per acre, or practically $0.0196 per box, in favor of the orchards under alfalfa management. (See Table XXI.)

Owing to the fact that so few have been in alfalfa for any length of time and that the management of these orchards was more or less in a transitory state, it was impossible to obtain adequate complete data on this subject. A more extended investigation would be necessary to determine the relative merits of the two methods of management.

TABLE XXI.—*Labor and cost chargeable per acre prior to harvest on orchards under mulch-crop management (30 ranches).*[1]

Operation.	Hours per acre.		Cost per acre.			Cost per box.
	Man.	Horse.	Man.	Horse.	Total.	
Cultivation	11.74	21.47	$2.94	$3.22	$6.16	
Irrigation	35.66		8.92		8.92	
Labor on mulch crop	16.64	9.67	4.16	1.45	5.61	
Manuring	4.32	7.92	1.08	1.19	2.27	
Pruning	40.31		10.08		10.08	
Hauling brush	11.86	14.46	2.97	2.17	5.14	
Propping	19.01	10.73	4.75	1.61	6.36	
Thinning	53.29		13.32		13.32	
Spraying (lime-sulphur)	8.13	5.42	2.03	.81	2.84	
Spraying (lead-arsenate)	19.99	13.45	5.00	2.02	7.02	
Miscellaneous	9.06		2.27		2.27	
Total	230.01	83.12	57.52	12.47	69.99	$0.1029

[1] All items of labor, except cultivation, irrigation, and labor on mulch crop, are the same as under clean-cultural management. A credit of $9 is given for 1 ton of alfalfa per acre.

HANDLING THE CROP.

Handling the crop includes all harvesting labor necessary to deliver the packed box to a local association or a railway station. This labor consists of hauling apple-box shooks to the ranch, making the apple box, picking, hauling empty and full boxes to and from the orchard during harvesting, all packing-house labor, and the delivery of the packed box to the local association or the railway station. The total handling charges are about 23 per cent of the total cost of production. The various steps in the handling of the crop will be discussed in the usual order of their occurrence. All apples for shipment are packed in the standard Northwest box, the inside measurements of which are 10½ by 11½ by 18 inches.

HAULING SHOOKS.

In preparing for harvest the orchardist usually hauls a part or all of his box shooks to the ranch the latter part of the summer previous to the beginning of harvest. Many orchardists haul a portion of their shooks on return trips from hauling packed boxes to the shipping point during harvest time. Some buy box shooks on contract, delivered at the ranch. Others buy them and pay a stipulated price for delivery. This price of course varies with the distance the shooks are hauled. A crew of 1 man and 2 horses will haul approximately 477 box shooks a distance of 1.83 miles in two hours. The average cost per mile per shook for hauling is $0.002 and the average distance hauled is 1.79 miles. A crew of 1 man and 1 horse is sometimes used for hauling shooks, but there were not enough records of this method to give a reliable average.

BOX MAKING.

The boxes are usually made by the orchardist and members of his family if the number necessary for the crop is not too large. Where boxes are made by contract there is a charge of $0.0075 to $0.01 per box.

PICKING.

Picking is usually begun on the Jonathans about the 1st of September and ends with the Winesaps along in November. Picking is done by hand into buckets of various kinds. The galvanized one-half bushel bucket is most common, although some use a galvanized-iron bucket with a canvas bottom which may be opened to allow the

FIG. 5.—Picking Grimes Golden apples. Showing one type of ladder used for picking in the valley.

fruit to pass into a picking box without injury. The pickers ordinarily work from orchard ladders and stepladders varying in length from 8 to 10 feet. (See fig. 5.) On account of the size of the trees, it is seldom necessary to use a ladder over 14 feet in length. Some varieties are picked two or three times. Where ripening is irregular among the red varieties, orchardists pick the apple when it approaches a correct stage of ripeness and has obtained the proper color. It is not customary to pick apples by contract per box. All picking is done by day labor at from $2.25 to $2.50 per 10-hour day. The apples when picked are placed in packing boxes which previously have been scattered at convenient places throughout the orchard. The average picker will pick from 50 to 80 loose boxes per day. The average for all records was 71.6 loose boxes, or 49.73 packed boxes, per 10-hour day, at a cost of $0.0503 per packed box.

HAULING APPLES TO PACKING SHED.

Prior to and during the picking season empty boxes are hauled and scattered at convenient places for the pickers throughout the orchard. The boxes in which the apples are placed to be hauled to the packing shed are the same or similar to the ones in which the apples are packed. A wagon or sled with one or two horses is used in hauling the boxes to and from the orchards. A crew of 1 man and 1 or 2 horses is generally used for hauling the apples. (See Table XXII.)

TABLE XXII.—*Cost of hauling to packing house under different methods.*

A.—SLED.

Number of— Men.	Number of— Horses.	Hours per load.	Loose boxes per load.	Cost per packed box.
1	2	0.54	30.2	$0.0147
1	1	.403	15.6	.0155

B.—WAGON.

Number of— Men.	Number of— Horses.	Hours per load.	Loose boxes per load.	Cost per packed box.
1	2	0.745	42.2	$0.0146
1	1	.675	29.5	.0137

Regardless of crew with wagon or sled, the cost per packed box of hauling boxes to and from the orchard is $0.0144.

PACKING.

All apples are usually packed in a packing house, a barn, or a shed ordinarily used for other purposes. (See fig. 6.) But little sorting, grading, and packing is done in the orchard. All fruit is packed as soon as possible after it is picked. An occasional grower may store a few of the late varieties in a cool place and pack them during the winter.

The size of the crew employed in the packing is usually governed by the size of the crop. As most of the orchards are small, much of the work is done by the orchardist and members of his family. Where the orchards and crops are large it is necessary to employ several sorters and packers, with the necessary additional help. In the larger packing houses there are usually employed men whose duty it is to supply the packers and sorters with boxes, paper, and fruit, and to carry away the packed boxes. These "waiters" deliver the fruit to a man, who nails and stamps the box. Where there are a small number of packers and sorters one man may wait on the packers and do the nailing.

All fruit is sorted; sometimes by the men as they pack, sometimes by a person especially employed for this purpose. The sorters usually sort the fruit from the loose boxes into three grades: Extra Fancy, Fancy, and Choice. The culls are thrown into boxes close at hand. In some instances the fruit is placed on canvas packing tables and sorted in a similar manner. Some of the growers who harvest the largest crops use mechanical sizers, but when this investigation was made so few men had adopted this method of sizing that it was impossible to obtain enough data to give reliable averages. Both men and women are employed in sorting and packing. One person will sort from 50 to 100 boxes per day. The sorters are paid $0.225 to $0.25 per hour for labor.

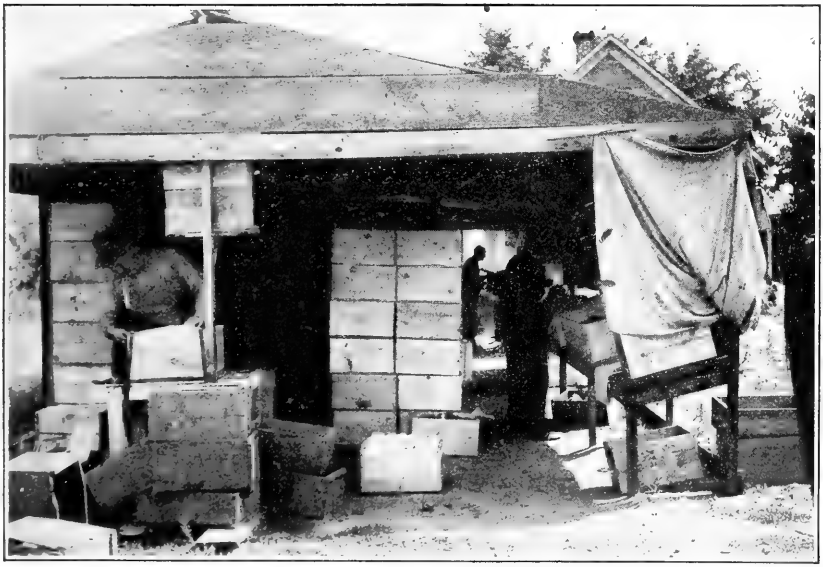


FIG. 6.—Packing apples in the Wenatchee Valley. This type of packing shed is not uncommon on many of the smaller ranches.

It is the usual practice to line all boxes with paper before packing. All grades of apples are wrapped. As previously stated, the packer may both sort and pack, or may merely pack sorted fruit. Over 64 per cent of the growers practice the former method. A man will sort and pack 69 boxes in 10 hours, whereas a man who packs sorted fruit will average 76 boxes in the same time. The former receives $0.07 per box, while the latter receives $0.06. Three loose boxes, as they come from the orchard, usually pack out two boxes. The cost of each operation or combination of operations in handling the fruit has been distributed over all records, so that the resulting cost per box is an average for all ranches. (See Table XXIII.)

TABLE XXIII.—*Items considered in figuring packing-house charge (87 ranches).*

Operation.	Cost per box.	Operation.	Cost per box.
Sorting and packing	$0.07	Sorting	$0.0278
Packing sorted fruit	.06	Stamping and nailing	.0083
Nailing and "waiting"	.0166	Foremen's supervision	.0030

The average packing-house charge, figured from the above averages, was $0.087 per packed box.

FIG. 7.—Hauling apples to station. There are 118 boxes in this load. The average load hauled with a 1-man and 2-horse crew is 89.69 boxes.

HAULING PACKED BOXES.

During harvesting the apples are usually delivered to a local association or a shipping point. The majority of growers do their own hauling. Eighty-one followed this practice, 68 with a crew of 1 man and 2 horses, and 13 with a 1-man and 1-horse crew. The load varies from 70 to 130 boxes with the former and from 30 to 70 boxes with the latter. (See fig. 7.) Four of the growers contracted to have their apples hauled, the price per box varying from $0.01 to $0.03 with the distance. Two loaded their apples directly on cars, a railroad siding being close at hand. The crew doing the hauling was governed to some extent by the distance to the point of delivery. (See Table XXIV.)

TABLE XXIV.—*Hauling to shipping point—Average distance and time and boxes per load for each crew.*

Number of records.	Number of—		Miles.	Hours per load.	Boxes per load.
	Men.	Horses.			
68	1	2	1.78	2.37	89.69
13	1	1	1.32	1.42	46.53

Where all records were considered, the average cost for hauling per mile per packed box was $0.0082.

CULLS.

A problem worthy of much consideration by the growers of the valley is that of the disposition of apples which are not packed for market.

As in many other apple-producing regions, growers do not believe that the money received for the cull fruit pays them for the handling. This requires, in many regions, the picking of culls from the ground. There are, however, many apples which are culled in the packing house during sorting and packing.

The handling of this grade of apples has been adversely affected in more ways than one. In a short-crop year when prices are good the growers do not feel the necessity of handling the culls for the prices which the owners of the by-product plants will pay. In years of low prices, which are generally years of large crops, the by-product company usually is not able to handle the whole cull crop of a district. This condition has been unfavorable to the development of the by-product industry. No doubt there are many other factors which are equally important in discouraging its advancement. In this study no account has been taken of the cull apples, since at the time when the survey was made there was no important by-product plant in the valley.

Wayne County, N. Y., produces very large quantities of dried apples. Many of the farms there are small, but it is not uncommon for the orchardist to own and manage his own drier plant in connection with his regular farm business. Some orchardists who do not have enough drier stock of their own find it easy to buy sufficient quantities at reasonable prices from their neighbors. The initial investment is not great. Such a plan might prove of interest and value to the growers of Wenatchee Valley.

LABOR COSTS.

The total labor cost in clean cultivated orchards was $179.09 per acre, or $0.3020 per box. The labor cost prior to harvesting amounted to $72.64 per acre, or $0.1225 per box. This cost was approximately 40 per cent of the total labor cost. Table XVIII gives the summary of the various items which make up the total labor chargeable per acre prior to harvesting in orchards under clean cultural management.

TABLE XXV.—*Labor cost for harvesting (87 ranches).*

Item.	Hours per acre.		Cost per acre.	Cost per box.
	Man.	Horse.		
Hauling shooks (average distance hauled 1.79 miles)	3.81	7.18	$2.04	$0.0034
Making boxes	17.8		4.45	.0075
Hauling empties to and from orchard	17.95	26.90	8.52	.0144
Hauling full boxes (average distance 1.70 miles)	15.96	28.46	8.26	.0139
Foreman charge [1]			1.78	.0030
Picking	119.24		29.81	.0503
Sorting, packing, stamping, and nailing			51.59	.0870
Total	174.76		106.45	.1795

[1] Twenty records:

Average crew	5
Average number of days per acre for harvesting crop	11.9
Foreman days per acre	2.38
Foreman wage per day	$3.25
Cost per acre	$7.75
Twenty-three per cent of records use foreman; 23 per cent × $7.75 = $1.783.	
Foreman charge per acre	$1.78

The labor cost for harvesting amounted to $106.45 per acre, or $0.1795 per box. This cost was approximately 60 per cent of the total labor cost. Table XXV gives the summary of the various items which make up the total labor cost for harvesting. Table XXVI gives the total annual labor cost per acre, per box, and per tree.

TABLE XXVI.—*Total labor cost per acre, per box, and per tree (87 ranches).*

Item.	Total labor cost.		
	Per acre.	Per box.	Per tree.
Labor before harvest [1]	$ 72.64	$0.1225	$0.8968
Labor before harvest [2]	60.99	.1028	.7406
Harvesting labor	106.45	.1795	1.314
Total labor (clean culture)	179.09	.3020	2.211
Total labor (alfalfa)	167.44	.2823	2.067

[1] Labor before harvest where only clean cultivated orchards are considered.
[2] Labor before harvest where only alfalfa orchards are considered; credit is given for 1 ton of alfalfa per acre at $9 per ton.

MATERIAL COSTS.

Material costs include all material such as box shooks, nails, etc., together with anything else for which cash, or its equivalent, must be used. A manure charge was made against the entire orchard for the amount applied each year, whether on a part or the whole of the orchard.

Labels are put on the boxes of the extra fancy and fancy grades. No accurate information as to the percentage of extra fancy and fancy fruit was obtained. The growers estimated approximately 70 per cent. The price of high-grade labels does not vary much if purchased in large lots. In some instances the fruit is labeled before delivery to an association or shipping point. When the labels are furnished and applied by the association, a charge of 1 cent per box is usually made. The label cost as a whole appears under material costs, for it was difficult to determine the time required for labeling. Other material costs are shown in Table XXVII. These costs are $103.71 per acre, amounting to $0.1749 per box, or 22.40 per cent of the total box costs.

TABLE XXVII.—*Material costs in 1914 (87 ranches).*

Item.	Cost per acre.	Cost per box.
Box shooks	$62.27	$0.1050
Nails	1.48	.0025
Paper	16.82	.0284
Labels [1]	5.93	.01
Lime-sulphur	8.41	.0142
Lead-arsenate	4.74	.0080
Manure	3.46	.0058
Gasoline and oil	.60	.0010
Total	103.71	.1749

[1] Includes putting on of the labels.

FIXED COSTS.

The term "fixed costs" includes all costs other than labor and material costs that enter into and make up the total cost of production. Under this heading come such items as taxes, insurance, and machinery depreciation. These fixed costs are shown in Table XXVIII. The tax and insurance charges per acre, other than water tax, on the bearing apple orchard are found by prorating the total tax and insurance on the entire ranch in the proportion that the apple orchard is of the total investment.

The water tax of $1.69 per acre is the average of the rates in force on the various ditches, ranging from $1.50 to $3.50 per acre. This rate varies from year to year, depending upon the ditch.

The interest on investment is figured at the prevailing rate (8 per cent) on the estimated value of the bearing apple orchard land as given by the rancher at the time this investigation was made.

The charge for use of equipment is computed by considering the interest 8 per cent, depreciation 11 per cent, taxes 1 per cent, and repairs 5 per cent, which amounts to an annual charge of 25 per cent on the total equipment investment.

The charge for the use of the packing house is computed by considering the interest at 8 per cent, depreciation at 3 per cent, taxes 1 per cent, and repairs 3 per cent, which amounts to 15 per cent on the total packing-house investment.

No account has been taken of the depreciation of the orchards themselves, as the average length of life of the commercial varieties under the methods of management in vogue here is not known. However, in arriving at the true cost of apple production such a charge should be considered.

TABLE XXVIII.—*Fixed costs, 87 orchards.*

Item.	Cost per acre.	Cost per box.
Taxes	$13.08	$0.0221
Water tax	1.69	.0028
Insurance	.96	.0016
Interest on investment	154.00	.2597
Equipment charge	10.42	.0176
Packing house building charge	6.78	.0114
Total	186.93	.3152

The various annual costs of producing apples in the bearing orchards studied in Wenatchee Valley, including delivery at shipping point, are summarized in Table XXIX. The fixed, or overhead, cost is 40 per cent, while the labor and material costs are respectively 38 and 22 per cent of the total cost of production.

TABLE XXIX.—*Summary of labor, cash, and fixed costs per acre (clean-cultivated orchards).*

Items of cost.	Total cost.			Per cent of total cost.
	Per acre.	Per box.	Per tree.	
Labor	$179.09	$0.3020	$2.211	38.13
Material	103.71	.1749	1.280	22.08
Fixed cost	186.93	.3152	2.308	39.79
Total	469.73	.7921	5.799	100.00

The largest single charge that enters into these totals is that of interest on investment, which is 33 per cent of the total. This leaves about 67 per cent for all other costs, so that in considering only those expenses which the average rancher usually would calculate, the production of a box of apples is shown to cost on the farms studied in the valley about 50 cents.

Considering costs in that way, however, gives a misleading figure, for the calculation leaves out not only several items, but the largest single item, that of interest on investment, which in the case of the farms studied is nearly 26 cents per box. When this and other charges are considered it is found that the average cost of producing apples on the farms studied in the Wenatchee Valley having bearing orchards under clean cultural management in 1914 was $0.7921 per box. In orchards under mulch-crop management the cost is approximately $0.02 per box less.

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WM. A. TAYLOR, Chief

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WATER PENETRATION IN THE GUMBO SOILS OF THE BELLE FOURCHE RECLAMATION PROJECT.

By O. R. MATHEWS, *Assistant, Dry-Land Agriculture Investigations.*

CONTENTS.

	Page.
Introduction	1
Description of the gumbo soil of the Belle Fourche Reclamation Project	2
Water capacity of the gumbo soil	3
Productivity of the gumbo soil	3
Changes in the volume of the soil due to wetting and drying	3
Rate of movement of water in loose, saturated soil	4
Rate of movement of water in wet soil under field conditions	5
Penetration of water into dry soil in the field	6
Summary	11

INTRODUCTION.

The readiness with which water penetrates into any soil determines to a great extent the amount that will be available to crops. An accurate knowledge of water movement within a soil often furnishes an indication of the farm practices that will be most successful. Thus under irrigation the rapidity of water percolation may determine in what way and at what time water may be most effectively applied. On dry land a knowledge of moisture movement often shows what results may be expected from different cultural methods calculated to increase the quantity of water entering the soil.

The gumbo soil of the Belle Fourche (S. Dak.) Reclamation Project offers problems in water penetration materially different from those in soils of other types. These differences are due largely to its peculiar physical characteristics.

This bulletin presents the results of certain studies of the penetration of water into the gumbo soils of the Belle Fourche project.

Knorr,[1] working on the sandy loam soils at Scottsbluff, Nebr., found that plats irrigated in the fall were more moist and moist to greater depths in the spring than plats not fall irrigated. When

[1] Knorr, Fritz. Experiments with crops under fall irrigation at the Scottsbluff Reclamation Project Experiment Farm. U. S. Dept. Agr. Bul. 133, 17 p., 5 fig. 1914.

irrigated during the following summer, the moist soil absorbed water much more readily than the dry soil. The dry soil required a longer flow of water to saturate it to a depth of 18 inches than did the soil containing more moisture. By irrigation, the water content of the moist soil was increased to a depth of 6 feet, while the dry soil showed no increase in water content below the second foot. Continuing the flow of water on the dry soil in order to get water into the lower depths was tried, but was discontinued for the reason that the dry soil absorbed the water so slowly that a large amount of the flow was lost by run-off.

The results obtained by Knorr on the sandy loam soils and those obtained from the experiments described in this paper on the gumbo soils are strikingly different. They bring out clearly the impracticability of trying to use the same methods on all soils. The character of the soil is an important factor in determining the degree of success of any method of water application.

DESCRIPTION OF THE GUMBO SOIL OF THE BELLE FOURCHE RECLAMATION PROJECT.

The soil of the Belle Fourche Reclamation Project is a very heavy clay of the type classified by the Bureau of Soils as Pierre clay.[1]

The United States Bureau of Soils, in a reconnoissance soil survey of western South Dakota, found that the soils of this type covered about seven and three-quarter million acres in South Dakota, or about 30 per cent of the total area surveyed.[2] It is a residual soil, formed by the decomposition of shale, the partly decomposed shale being found at a depth of approximately 4 feet below the surface. This depth varies considerably with the location.

Fine soil particles make up the greater portion of the soil. A mechanical analysis of the surface soil of this type shows that soil particles of the different sizes are present in the percentages shown in Table I.

TABLE I.—*Mechanical analysis of Pierre clay.*[a]

Soil.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pierre clay	0.2	1.1	1.4	5.5	13.0	43.2	35.0

[a] Strahorn, A. T., and Mann, C. W. Op. cit.

Analyses of the subsoil are not available, but the textures of the second foot and third foot indicate that the percentage of clay at

[1] Strahorn, A. T., and Mann, C. W. Soil survey of the Belle Fourche area, South Dakota. U. S. Dept. Agr., Bur. Soils [Adv. sheets—Field Oper., 1907], 31 p., 1 fig., 2 maps. 1908.

[2] Coffey, G. N., and others. Reconnoissance soil survey of western South Dakota. U. S. Dept. Agr., Bur. Soils [Adv. sheets—Field Oper., 1909], 80 p., 2 fig., 7 pl., 1 map. 1911.

these depths may be somewhat higher than in the first foot. The difference is not great, and as a whole the mechanical composition of the first 3 feet may be considered uniform.

WATER CAPACITY OF THE GUMBO SOIL.

The water-carrying capacity of this soil is high, and the minimum point to which crops can utilize the water is correspondingly high. The soil, when filled, will carry about 30 per cent of water, of which about 15 per cent is available for the use of crops. The character of the soil is such, however, that the crops do not root deeply, owing either to the lack of water in the lower depths or to the impervious nature of the soil. In spite, therefore, of the large quantity of water that can be obtained by the crop from the soil near the surface, the shallowness of feeding materially reduces the quantity of water actually available.

PRODUCTIVITY OF THE GUMBO SOIL.

The producing capacity of the soil is high. There is no evidence of a deficiency of any mineral element essential to crop production. When sufficient water is supplied, abundant crops are obtained. The high productive capacity of this soil is evidenced by the yields obtained on plats not irrigated in 1915, when the rainfall was unusually favorable both in amount and in distribution. The average acre yields obtained were 72.2 bushels of barley, 36.2 bushels of winter wheat, 57.6 bushels of spring wheat, 125.6 bushels of oats, and 44.5 bushels of corn.

CHANGES IN THE VOLUME OF THE SOIL DUE TO WETTING AND DRYING.

The large amount of clay present makes this soil subject to extreme changes in volume with changes in its water content. When the soil is wet it swells and compacts; when dried it shrinks and cracks. That the change in volume is great enough to cause a material change in physical structure is shown by the results of the following experiment, which was made for the purpose of obtaining a measure of this change.

The volume of oven-dried compact samples of soil was determined. These samples were then immersed in water and allowed to expand freely and the volume redetermined. The volume of the soil from the first foot increased 2.2 times. The volume of that from both the second and third feet increased 2.5 times.

These changes in volume, due to variations in moisture content, result in the following structural differences:

When dry this soil is usually covered with a natural mulch about 2 inches deep caused by the crumbling of the surface soil. Beneath this mulch is a layer of soil honeycombed with cracks. The number of these cracks and the depth to which they extend depend somewhat upon the manner in which the soil has been dried. Where a close-drilled crop has been grown, they are small and numerous and break the soil into small lumps to a depth of about 15 inches. Below this depth the soil is generally compact and practically free from cracks, no matter how dry it may be.

When the soil becomes wet it expands, and thus the cracks are closed. When any excess of the expanding force in the cracked layer occurs, the whole force of expansion in the uncracked area has the effect of crowding the soil particles closer together. For this reason the wet soil is always compact throughout and free from open spaces.

Considering these structural differences between the wet and the dry soil, it can readily be seen that the moisture content of the soil may have a great influence upon water movement; but a study of water movement in both the wet and the dry soil is necessary in order to obtain information as to how water penetration takes place under actual field conditions.

On the Belle Fourche project it has been found in field practice that the water content of the surface soil at the time the water is applied determines to a great extent the quantity that will be absorbed, especially when the water is applied rapidly. When both the surface soil and the subsoil are dry, over an inch of rain, even if it comes in a torrential manner, will be absorbed with very little loss, because much of the water makes its way into the soil through the cracks. On the other hand, when the surface soil is wet these cracks are closed and a rain of as little as one-fourth of an inch may be largely lost by run-off. Any rain falling on a wet surface must fall very slowly in order to be absorbed.

That the condition of the surface soil determines the amount of water absorbed is especially true when irrigation water is applied. A comparatively small rain, by wetting the surface and causing the cracks to close, often stops irrigation. There are times when it is possible to irrigate successfully in the afternoon, when an attempt to irrigate during the forenoon of the same day has resulted in the run-off of practically all the water applied.

These facts indicate that water movement through this soil when wet is very slow.

RATE OF MOVEMENT OF WATER IN LOOSE, SATURATED SOIL.

In order to make actual determinations of the rate at which water moves in this soil when it is saturated, the following experiment was performed:

Sections of blotting paper were fitted, as bottoms, into a number of cans that were open at both ends. Each can was filled with a composite sample of a foot section of soil and then immersed in water. After the soil had become thoroughly saturated the cans were removed from the water and placed upon a screen. All the soil was then removed except a 3-inch layer in the bottom of each can.

The time taken for an inch of water to pass through these 3-inch layers of saturated soil was four hours for the first-foot sample and 12 hours for the second-foot sample. These results show that water moves slowly in the saturated soil. The rate of movement in these samples is not the same as that under field conditions, because in the field the soil is confined and can not swell freely and is therefore more compact than the soil in these cans.

RATE OF MOVEMENT OF WATER IN WET SOIL UNDER FIELD CONDITIONS.

To determine at what rate water moves in the wet soil under field conditions, the following experiment was performed on a plat that had been fallow for several seasons. The soil in this plat was wet

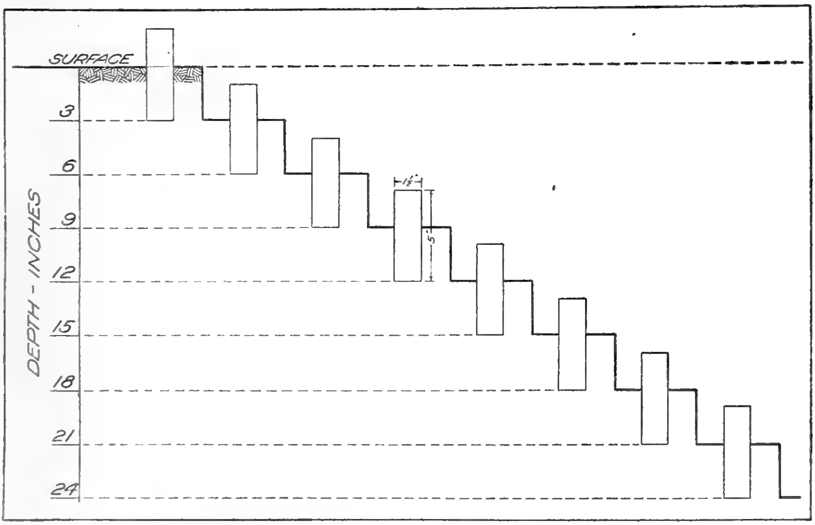

FIG. 1.—Diagram showing the method used to obtain samples of undisturbed soil from different depths by means of brass tubes.

and compact to a depth of over 3 feet. Samples were taken by means of brass tubes 1½ inches in diameter and 5 inches long, in the manner shown in figure 1.

Each of these tubes when removed was found to contain between 2 and 2½ inches of soil. After being removed, the tubes were immersed in water in order that they might become thoroughly moistened. They were then placed in an upright position on a blotter and filled with water. The rapidity with which water passed into the soil was then recorded. In the tubes containing the soils from the surface, water passed into the soil at the rate of about 1 inch in 12 hours. In all the others the rate was uniformly much slower. No differences in the rapidity of water movement were shown between any of the samples taken at any of the various depths below

3 inches. In all of the tubes containing soil taken from below the first 3 inches the water level fell less than one-eighth of an inch in 48 hours, and part of this was due to evaporation.

The smallness of the tubes used may have caused some compacting during the process of sampling; also the plat sampled was undoubtedly more compact than one that had not been continuously fallowed. For this reason a part of the experiment was duplicated on land that had been fallow for only a few months. Samples were taken with tin cans 5 inches in diameter and with thin cutting edges. By this means samples were taken from the surface and from depths of 3 and 6 inches without any mechanical compacting of the soil in sampling. The penetration in these cans was then studied in the same way as in the brass tubes. Water passed through the surface 3 inches at the rate of 1 inch in two hours. For the other sections the rate was at least as slow as in the brass tubes. Evidently the soil in the brass tubes was not compacted enough to make any material difference in the rate of penetration except in the surface section. Even in this section the difference in the rate was probably due in part to the fact that in the field the surface soil in the second plat was considerably looser than in the first one sampled.

The extreme slowness with which water passed into these sections proves that water movement in a wet soil of this type in the field is exceedingly slow. That this slowness is partly due to the natural compacting of the soil by swelling is shown by a comparison of the rate at which water moved through soil under natural conditions with the rate at which it moved in a saturated soil that was allowed to expand freely, as is shown in the first experiment. At any rate, water movement in this soil when it is wet is so slow as to be practically negligible in field practice.

PENETRATION OF WATER INTO DRY SOIL IN THE FIELD.

The experiments already described indicated that in this type of soil a dry condition was most favorable for water movement. In order to measure the maximum water penetration in the soil, a number of experiments were made on a plat that was extremely dry. The plat was covered with a very thin dust mulch. Beneath the mulch the soil was cracked into very small lumps to a depth of 15 inches; below 15 inches it was very hard, dry, and compact.

The first experiment in this series was made for the purpose of determining the permeability of the soil at various depths. For this purpose, borings 8 inches in diameter, extending below the surface to depths of 6, 9, 12, 15, 18, 21, and 24 inches, were made. Two gallons of water was then poured into each hole. A like quantity of water was applied to an equal area at the surface by means of a tin can set 1 inch into the soil.

The time required for the water to disappear from each hole and the depth to which it penetrated, as measured both from the bottom of the hole and from the surface of the ground, is shown in Table II.

TABLE II.—*Time required for 2 gallons of water to disappear from 8-inch holes bored to different depths in the soil and the depth to which the water penetrated.*

Specification.	Hole No.							
	1	2	3	4	5	6	7	8
Depth of hole .... inches..	Surface.	6	9	12	15	18	21	24
Time required:								
Minutes	4	36	39	100	....	....	....	....
Hours	....	....	....	....	18	23	30	24
Depth of soil penetrated .... inches..	16	19	16	10	6	4½	5	6
Depth below surface to which water penetrated .... inches..	16	25	25	22	21	22½	26	30

As the line of demarcation between the wet and the dry soil was always very sharp, the exact depth of penetration was easily de-

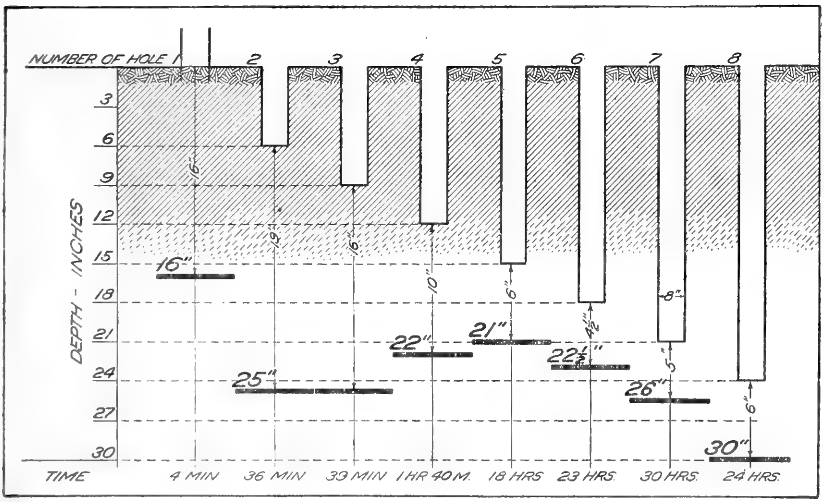

FIG. 2.—Diagram showing the time required for 2 gallons of water to disappear from holes 8 inches in diameter bored to different depths in the soil and showing also the depths to which it penetrated. The heavy lines indicate the lowest points reached by the water from the different holes. The heavy figures below each hole indicate the total distance from the surface and the light figures the distance below the bottom of the hole.

termined. The plan of the experiment and the results are shown graphically in figure 2.

A study of Table II and figure 2 shows that, at least for the cracked area, the time required for the water to disappear depended upon the distance from the surface of the point of application. No doubt, this was because the water applied near the surface escaped through cracks in the soil. That this was the case is shown by the wide differences between the cracked and uncracked layers as to the time required for the water to disappear. In all parts of the uncracked area water disappeared very slowly.

Water penetrated to practically the same depth from the surface in all the holes except the first and the last. In all the holes except the first, water evidently penetrated to a point where further movement took place with difficulty. That the water applied at the surface did not reach the depth where movement was difficult was doubtless due to the fact that the quantity of water was not sufficient to reach that depth. The fact that the water from most of the holes penetrated to a depth of from 21 to 25 inches below the surface would indicate that a layer of impervious soil exists at that depth

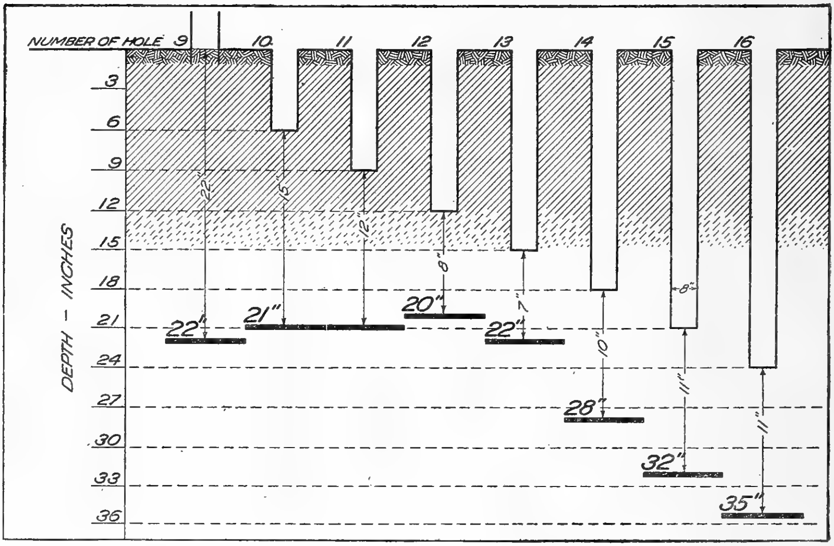

FIG. 3.—Diagram showing the depth of soil penetrated and the total distance from the surface reached when water was kept standing for 10 days in holes 8 inches in diameter bored to different depths. The heavy lines indicate the lowest points reached by the water from the different holes.

were it not for the fact that water added at about this depth penetrated through as many inches of soil as did that introduced 9 inches higher. The depth to which the water penetrated in all holes in the compact layer indicates that the water movement throughout this portion of the soil was very uniform.

A second experiment was made to determine the distance to which water introduced into the soil at various depths would penetrate in a given length of time. For this purpose a set of borings duplicating those in the previous experiment was made, and water was kept standing in each of them for a period of 10 days. At the end of that time the depth to which the water had penetrated was measured. The results of this experiment are shown in Table III and figure 3.

TABLE III.—*Depth of soil penetrated and total distance from the surface reached where water was kept standing for 10 days in holes 8 inches in diameter bored to different depths.*

Specification.	Hole No.							
	9	10	11	12	13	14	15	16
Depth of hole............inches..	Surface.	6	9	12	15	18	21	24
Depth of soil penetrated.....do....	22	15	12	8	7	10	11	11
Depth below surface to which water penetrated..............inches..	22	21	21	20	22	28	32	35

Water added at all points within the cracked area penetrated almost exactly the same distance. In each case it penetrated through the cracked soil and about 7 inches into the compact soil beneath. Where water was applied below the cracked area the total distance reached by water penetration varied with the depth below the surface at which the water was applied. The distance that it penetrated into the compact soil was quite uniform. That a constant, though exceedingly slow, movement of moisture did take place in the compact layer is shown by a comparison of Tables II and III. These show that for all the points within the compact layer the depth penetrated when water was kept standing for 10 days was greater than when it stood for a shorter period of time.

A third experiment was performed in order to determine as nearly as possible the rapidity with which water movement takes place within this compact layer and the depth in it to which varying amounts of water would reach. A third series of borings was made to a uniform depth of 18 inches. The amount of water added, the time required for the water to disappear, and the depth to which it penetrated are shown in Table IV and figure 4. The distance that the water penetrated in each case was determined as soon as possible after the water disappeared.

TABLE IV.—*Time taken for various quantities of water to disappear and the depths of penetration in each case from the bottoms of a series of holes 18 inches deep.*

Specification.	Hole No.							
	17	18	19	20	21	22	23	24
Water added:								
Quarts..........................	1	2	....	....	....	....	....	....
Gallons.........................	....	....	1	1	2	2	4	[a] 2
Time required to disappear:								
Hours...........................	....	3	5	32	48	57	43	....
Minutes.........................	5	10	40	40	30	30	....	....
Days............................	....	....	....	....	....	....	....	10
Depth of penetration below the bottom of the hole............inches..	5	6	3	5	5½	5½	5	6½
Depth of penetration below the surface.....................inches..	23	24	21	23	23½	23½	23	24½

[a] Three times.

The smaller quantities of water penetrated practically as deep as the larger amounts that stood for a much longer time. In five minutes the water in hole No. 17 penetrated to a depth as great as was reached by that in some of the others in several days.

There is an apparent lack of consistency in the time required for some of the larger quantities of water to disappear. This is due to the fact that in some cases the amount of water added was sufficient to raise the water level to a point that allowed it to escape laterally through the cracked soil. This is shown also by the lack of difference in the depth of penetration of the different quantities. The best measure of time and depth of penetration is found in hole No. 24, in which a supply of water was maintained by the addition of 2 gallons at three separate times. Ten days were required for the

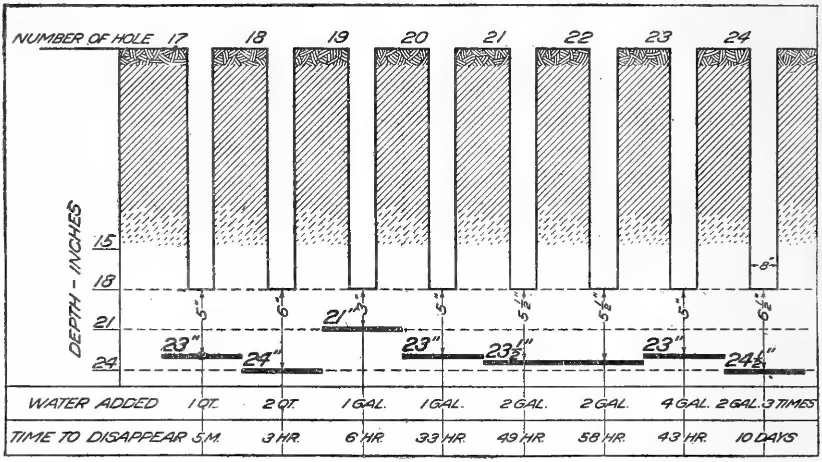

FIG. 4.—Diagram showing the time taken for various quantities of water to disappear and the depth of penetration in each case from the bottoms of a series of holes 8 inches in diameter and 18 inches deep. The heavy lines indicate the lowest points reached by the water from the different holes.

disappearance of the entire quantity, but the total depth of penetration during this time was only a little over an inch more than it was from those holes in which water stood for a much less time. These experiments indicate that while the water movement is comparatively rapid in the dry soil it is very slow in the wet soil.

Since there is no evidence of a layer of soil actually impervious to water, it appears that the exceedingly slow movement of water is due to the fact that the soil in contact with the water quickly becomes so swollen and compact that further movement of water within it is very difficult. Penetration into the dry soil almost stops, not because of the resistance offered by the dry soil itself, but on account of the extremely slow movement of the water through the layer of wet soil that is between the source of water supply and the dry soil.

That this slow movement in the dry subsoil is due to the compacting of the wet soil above is further shown by laboratory experiments on dry soil under field conditions. It was found that where the soil was allowed to swell freely the water would move at least an inch in five minutes in the heaviest section of the soil. Since the rate of movement under field conditions is so much slower, there is no doubt that the compacting of the wet soil in the field is so great that it renders any movement of water through it almost impossible. Water movement in the dry subsoil is therefore limited by the rapidity with which the water can make its way through the wet soil above.

SUMMARY.

Water movement in the gumbo soils of the Belle Fourche Reclamation Project may be summed up as follows:

On a dry soil, penetration takes places rapidly to a depth of about 2 feet because of the cracked condition of the soil near the surface. After the layer of easily penetrated soil becomes wet, it becomes so swollen and compact that it is nearly impervious, and further water movement is very slow.

The fact that moisture can move only very slowly in the wet surface soil would make it necessary to run water over the soil for a very long time in order that any considerable portion might be absorbed. This is not practicable, for the experiment with a dry subsoil showed that water from the surface penetrated almost as deep in a few minutes as it did in 10 days, so that the increase in the amount of moisture absorbed where the water stands for any considerable length of time over that taken in when the soil is simply covered would be so small as to be negligible. After a field has once been covered with water little benefit can result from having water continue to stand on or flow over the soil.

It is interesting to note the radical difference in water absorption between this soil and the sandy loam soil at Scottsbluff. The maximum rate of absorption is obtained on the wet soil at Scottsbluff and on the dry soil on the Belle Fourche project. These diametric differences apparently are due to the physical differences between the two soils and show clearly that a satisfactory practice on one type of soil may not be equally successful under other soil conditions.

The results of these experiments and observations can easily be applied in field practice, and recommendations for methods and practices may be based upon them.

The following points relative to the application of water by irrigation to these gumbo soils are clearly shown:

(1) Water should be applied only when the surface is dry.

(2) The quantity of water absorbed will depend upon the dryness and consequent cracked condition of the surface soil.

(3) After a field has once been covered with water, little further absorption takes place, and no benefit can result from having water stand on or flow over the soil for more than a few minutes.

(4) The depth to which the water will penetrate depends upon the depth to which the soil has been dried and cracked.

The following points brought out in this bulletin apply to the cultural practices for these gumbo soils under either irrigation or dry-land conditions:

(1) No particular method of cultivation will be superior to others in influencing the quantity of water absorbed, since this depends upon the degree to which the surface soil is dried and cracked. The soil after harvest is usually so dry that penetration takes place very readily, and any ordinary quantity of rain that falls is absorbed, regardless of the cultural treatment.

(2) Since the dry soil is naturally broken up to depths as great as would be reached by either deep plowing or subsoiling, these operations can be of no great benefit in water absorption.

(3) Some method, such as dynamiting, by which the soil below the cracked area could be broken up, might result in a temporary increase in the depth to which water could easily penetrate. The natural swelling of the soil, however, would cause it again to become compact every time it was wet. This would make it necessary for the operation to be repeated each year, which would involve an expense too great for this method ever to be considered seriously.

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BULLETIN No. 448

Contribution from the Bureau of Chemistry
CARL L. ALSBERG, Chief

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SEPARATION AND IDENTIFICATION OF FOOD-COLORING SUBSTANCES.

By W. E. MATHEWSON, *Assistant Chemist.*

CONTENTS.

	Page.
Introduction	1
General statements concerning reagents used in color analysis	2
Preliminary treatment of food products	4
Separation and purification of coloring substances	8
Identification of coloring substances	35

INTRODUCTION.

The scheme of analysis of dyes described in this bulletin embrace about 130 chemical individuals. This number comprises practically all those coal-tar colors (except a few entirely obsolete nitro dyes) which have been mentioned in the literature as having been found in food products, and those mentioned as being suitable for the coloring of foods. A number of dyes which are typical representatives of certain classes and which exemplify in a general way the analytical properties of certain groups, also have been included. No process for the analysis of dyes can be made so complete as to take into account all possible colors and combinations of colors; nevertheless the analyst should be prepared for as many as possible of the cases arising. It is especially difficult to take the newer colors into consideration, but, fortunately, at the present time these are very little used in food products.

The scheme of separation described is designed to meet actual conditions, one of which is the relatively more frequent occurrence of the eight colors the use of which in food is permitted by the United States Department of Agriculture[1] Amaranth, Ponceau 3 R, Ery-

[1] Food inspection decisions Nos. 76 and 164.

NOTE.—This bulletin will be of interest chiefly to chemists engaged in food analysis.

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throsin, Orange I, Napththol yellow S, Tartrazin, Light green S. F. yellowish, and Indigo disulfoacid—and among nonpermitted dyes of the oxy-monazo colors. An entirely different scheme might be preferable if, for instance, the difficultly soluble benzidin dyes were the most common colors.

The method for the separation of colors described in this bulletin is based mainly upon the employment of immiscible solvents. By this means most mixtures of the commonly occurring coal-tar dyes may be separated with relative ease. In dealing with the natural coloring substances the analyst is hampered by the lack of any exact knowledge concerning many of them, by the difficulty of obtaining pure preparations free from accompanying colored substances, by the lack of good methods for their quantitative estimation, and by the fact that little is known regarding the stability of many of them with the common reagents. Although the most important natural colors have been included in the tables, little attempt has been made to indicate means of separation other than by the methods more suitable for synthetic dyes.

Of the colors used in developing the methods described in this paper about 40 of the commonest were synthesized and purified in the laboratory. The physical and chemical properties of the others indicated their identity and proved that the samples were of sufficient purity for practical purposes.[1]

GENERAL STATEMENTS CONCERNING REAGENTS USED IN COLOR ANALYSIS.

The examination of food-coloring matters requires the frequent employment of some reagents that are not so often used in other kinds of chemical work. In addition to the ordinary acids and alkalies it is convenient for many purposes to have solutions of hydrochloric acid and of sodium hydroxid of accurately known strengths. Five-normal and tenth-normal hydrochloric acid and tenth-normal sodium hydroxid may be kept in stock bottles provided with attached burettes and guard tubes. Of the dilute solutions, eighth-normal is the most convenient concentration for use in separations, but tenth-normal solutions serve the purpose well and are to be preferred because of their greater suitability for titrations. A standard solution of five-normal sodium hydroxid is also needed and a portion may be kept in a 500-cc bottle, through the rubber stopper of which passes a graduated 10-cc pipette which is capped or closed above when not in use.

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[1] The coal-tar dyes have been designated in this bulletin by the numbers given in the tables in *A Systematic Survey of the Organic Coloring Matters*; by A. G. Green. Founded on the German of Drs. G. Schultz and P. Julius, second edition, London and New York, 1904. On page 56 have been given the corresponding numbers used by G. Schultz, *Farbstofftabellen*, Berlin, 1911–1914, and by Mulliken, *A Method for the Identification of Pure Organic Compounds*, vol. 3, New York, 1910.

The solutions named below are usually dropped from a pipette into the solutions under examination. For convenience they should be kept in bottles provided with glass caps ground on an enlargement of the neck. With this form of bottle a short graduated pipette (or piece of tubing) can be kept in the bottle under the cap. The solutions are:

Bromin water, 1 or 2 per cent. One per cent solution is about fourth-normal as oxidizing agent.

Hydrazin sulphate solution, 3.2 per cent (approximately normal as a reducing agent when oxidized to water and free nitrogen).

Sodium nitrite, 7 grams per 100 cc (approximately molecular normal).

Alpha-naphthol solution, from 10 to 20 per cent in alcohol. This solution is used in very small quantities and should be kept in a bottle of the same form as used for the other reagents but of smaller size. The solution becomes dark colored and unfit for use after standing some weeks.

Sodium hydrosulphite solution ($Na_2S_2O_4$, "Blankite"). This solution is unstable and is best prepared as needed. The writer prefers to use the powdered solid kept in a small bottle, in the cork of which is fixed a strip of sheet metal to serve as a spatula. With this arrangement the salt, which is very soluble, may be dropped, a few particles at a time, into the solution to be tested.

Potassium persulphate ($K_2S_2O_8$). The same observations apply here as under "Sodium hydrosulphite solution."

The following reagents should preferably be kept in some form of small dropping bottle: Concentrated hydrochloric acid, concentrated sulphuric acid, dilute hydrochloric acid (10 per cent), sodium hydroxid (10 per cent), ammonium hydroxid (density about 0.95), ferric chlorid (10 per cent), and stannous chlorid (40 grams in 100 cc concentrated hydrochloric acid).

Other reagents needed are: Solutions of alum, barium chlorid (or, better, barium acetate), uranium acetate or uranium sodium acetate, and sodium acetate. It is convenient to have the last-named solution approximately normal, 16 grams per 100 cc. A strong solution of lead acetate (normal, not the basic salt, 30 per cent) is used in considerable amount; and a rather carefully made 10 per cent sodium carbonate solution (double normal) is useful for separations of Orange I and for coupling reactions. Common salt solution made from C. P. sodium chlorid is useful for many separations. Two hundred and fifty grams per liter is a convenient concentration.

The following solvents are most frequently used:

Alcohol.

Amyl alcohol. This should be a good grade of "pyridin-free."

Gasoline or petroleum ether, "low boiling point," of density about 0.65. Commercial pentane, though expensive, may be preferred occasionally as a more homogeneous product of similar properties. The most objectionable of the impurities of gasoline may be removed by washing it a few times with concentrated sulphuric acid.

Ether. The alcohol in the commercial product may be removed by washing.

Dichlorhydrin. Most commercial C. P. products contain free acid. This is seldom harmful, but a freshly washed preparation may be preferred occasionally.

Ethyl acetate. Apparently this is usually impure and before use should be washed with water to remove alcohol, etc.

Amyl acetate. Amyl acetate is suited to the same uses as ethyl acetate. It is, however, a less active solvent for many dyes, partly, no doubt, because it dissolves less water. Commercial C. P. preparations show great variability, apparently from the presence of large amounts of impurities and not merely from difference in the proportion of isomers present. The impurities, especially amyl alcohol, are much more difficult to remove than those likely to be found in commercial ethyl acetate, so that the latter solvent has been used for the work described in this bulletin, notwithstanding its solubility and ease of saponification.

Anilin. Unless recently distilled, anilin is usually strongly colored; but the coloring matters present differ widely in solubility from the sulphonated dyes for whose separation it is most frequently employed. The colored impurities do not interfere further than by inconveniently masking the course of the fractionation.

Phenol. This must be colorless and should be free from mineral acid.

Carbon tetrachlorid.

Methyl alcohol.

PRELIMINARY TREATMENT OF FOOD PRODUCTS.

It is usually necessary to begin examination of the color or colored material by treatment with some solvent that will bring the coloring matter into solution.

Commercial food colors if soluble are dissolved directly in water, care being taken that the solution, to be examined according to the scheme described on pages 9 to 20, inclusive, be not made too concentrated. Solutions of suitable concentration contain from 0.05 to 0.01 per cent actual coloring matter. If the coloring matter is a powder, blowing some of the substance from the tip of a spatula over a sheet of moistened filter paper,[1] or over the surface of concentrated sulphuric acid contained in a flat porcelain dish, ordinarily will show if it is a mixture made from dry colors.

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[1] O. N. Witt, Z. Anal. Chem. **26** (1887), 100.

Candies, sirups, and other sugar products may be taken up directly with hot water.

Wines, liquors, and other alcoholic beverages may be first diluted and warmed on the water bath to remove alcohol. However, for the subsequent treatment with immiscible solvents it is not usually necessary that the alcohol be driven off as it is sufficient to dilute the sample to reduce the alcohol content to 10 per cent or less. This very often is preferable to heating the sample; but it must be borne in mind that the distribution of the coloring matters will be more or less modified by the alcohol.

Solid materials, such as fruits, flesh foods, etc., may be extracted first with 80 per cent alcohol, containing a very little acetic acid, to remove basic dyes, cochineal, etc., sensitive to alkalies. The pulp separated from the acid alcohol solution may then be digested with dilute alcohol of from 65 to 80 per cent strength, containing from 3 to 5 per cent of ammonia. If both extracts are colored it is easiest not to work them up separately, but to boil off the alcohol and ammonia from the second portion, and the alcohol from the first, and then combine them. This procedure is quite general in its applicability. However, with products colored with metallic lakes, such as those of the flavone and flavonol dyestuffs, the treatment with strong hydrochloric acid and amyl alcohol, suggested below, is perhaps more satisfactory. Lake pigments in many cases also can be washed off the surface of the food material, since they are most often used as facings. The washings are allowed to settle or are whirled in a centrifuge, and a portion of the sediment containing the lake is treated for identification of the color. Most lakes are decomposed, at least to a large extent, by hydrochloric acid and amyl alcohol.

From many solid products such as jams and meat pulp the common coloring matters, including the permitted dyes, can be extracted directly by adding concentrated hydrochloric acid and shaking thoroughly with amyl alcohol. The subsequent work is shortened and, with strongly colored materials especially, the plan is often quite satisfactory.

Wheat and rye products offer some difficulty in the extraction with dilute alcohol because of the solubility of the plant proteins, gliadin and hordein. In the case of macaroni, spaghetti, etc., boil the ammoniacal alcoholic extract containing the coloring matter until most but not quite all of the alcohol is removed. If the hot residue is of a semisolid consistency, it is best to add a little alcohol. It is then treated with about one-half of its volume of concentrated hydrochloric acid and is poured into a large separatory funnel. Amyl alcohol equal to about two-thirds of the original volume of the solution is added and sufficient salt solution to make the mixture separate well.

The amyl alcohol containing the color is washed a few times with a salt solution containing hydrocholoric acid to remove the protein; one separation with the centrifuge usually being desirable to free the solvent from the coagulum. The further treatment of the amyl alcohol solution is the same as that described under the heading Separation and Purification of Coloring Substances, page 8.

Dissolved coloring matters are generally separated from fats and oils by saponifying the fat or oil with alcoholic potash and extracting the coloring matter from the soap with gasoline or ether.[1] The manipulation of this process is not very convenient and, of course, all unsaponifiable matter remains with the color. It may be combined with advantage in many cases with one of the extraction methods with an immiscible solvent described below. A number of extraction methods are in use and probably each possesses advantages for certain colors.[2] Some dyes, as Anilin Yellow, may be extracted from oils conveniently with 90 per cent alcohol.[3] The method of Cornelison[4] (extracting the coloring matter with glacial acetic acid or with the same solvent containing a little added hydrochloric acid or water) will serve for the extraction of almost all the common oil-soluble dyes. Much oil dissolves in the acetic acid and a systematic fractionation is necessary; the different portions of extract being washed successively in several funnels containing a little gasoline.

The writer prefers the following procedure, which, though somewhat inconvenient, is quite generally applicable. It does not give a color entirely free from cholesterol and similar compounds. About 30 cc of the oil are diluted with about 120 cc of low-boiling gasoline, and this mixture is shaken out with several portions of a mixture of 90 parts of phenol with 10 of water. The volume of the first portion of solvent may be about 45 cc, the others 30 cc each. The phenol extract is washed in a separatory funnel with 2 or 3 portions of gasoline, then treated with sufficient cool, strong potassium or sodium hydroxid solution to dissolve the phenol. The dye is removed by shaking out the liquid with from 50 to 100 cc of ether. The ether is first washed a few times with caustic alkali solution to remove all phenol and finally with water. It may then be evaporated or treated further as indicated on pages 7 and 32–33.

The Sudan dyes are readily extracted by a mixture of 80 parts phosphoric acid (85 per cent, density about 1.70) and 20 parts concentrated sulphuric acid. The oil containing the dyes should be

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[1] See Gruenhut, Chem. Zentr. 69 (1898) II, 943.

[2] See Berry, U. S. Dept. Agr., Bur. Chem. Circ. No. 25; Doolittle, U. S. Dept. Agr., Bur. Chem. Bul. No. 65, p. 152.

[3] For the extraction and identification of Auramin (No. 425) when present in oils, see Frehse, Ann. fals 3 (1910), 293.

[4] J. Am. Chem. Soc. 30 (1908), 1478.

diluted with a few volumes of gasoline. Shaking out one or two times will usually be sufficient, but the method is not applicable to colors such as tolueneazo-β-naphthylamin, which are sensitive to strong acids. The alkali salts of Sudan G and of the coloring matter of annatto are readily soluble in water; hence these dyes are most easily removed by shaking out with dilute sodium or potassium hydroxid solution.

The extraction and separation of the dissolved coloring matters may be carried out together as follows: The oil or melted fat is diluted with gasoline and shaken out first with 2 per cent (half-normal) sodium hydroxid solution to remove annatto, Sudan G, and colors of similar solubility. The mixture is then washed several times, if necessary, with hydrochloric acid of from four to six normal strength, which will take out the aminoazo derivatives, such as Butter Yellow and aminoazotoluene. Benzeneazo-β-naphthylamin and tolueneazo-β-naphthylamin are extracted rather slowly by this treatment, the dyes apparently suffering rearrangement from the hydrazo-imin form into the true azo form before going into solution in the acid. Since the toluene derivative especially is rather rapidly decomposed by hydrochloric acid, the extracts should not be allowed to stand, but should be neutralized immediately. The Sudans and similar colors not extracted from the mixture by alkali or acid should be separated by one of the general procedures described on page 6, most conveniently with the phosphoric acid mixture. If the phosphoric acid solution, after washing once or twice with gasoline, be diluted and partially neutralized, the coloring matter in quite pure condition can be obtained by extraction with ether or gasoline.

Glycerol,[1] sodium salicylate [2] solution, and a mixture of these two have been recommended for the extraction of colors from some food products.

Microscopic examination of colored products usually gives useful information. This is especially true in certain cases for chemical tests under the microscope.[3]

Certain coloring matters can not be brought into solution by the methods outlined. Such substances are the organic pigments Indanthrene (No. 569) and unsulphonated indigo (No. 690), which are insoluble in all ordinary solvents and must be identified by their general properties. Lampblack and similar forms of carbon are characterized by insolubility in acids, alkalies, or hot dichlorhydrin, and by their complete combustibility. Ultramarine is stable toward alkalies but is very readily decolorized with acids with evolution of hydrogen sulphid, which may be detected with lead acetate paper.

[1] Klinger and Bujard, Z. Angew. Chem. (1891), 515.
[2] E. Spaeth, Z. Nahr. Genussm. 18 (1909), 587.
[3] Winton, A. L., *The Microscopy of Vegetable Foods.* New York, 1916.

Most other pigments not lakes are compounds with heavy metals and a suitable examination according to the ordinary methods of inorganic analysis will indicate the nature of the pigment.[1]

SEPARATION AND PURIFICATION OF COLORING SUBSTANCES.

PRELIMINARY TREATMENT.

By suitable preliminary treatment the coloring matter should be obtained in aqueous or dilute alcoholic solution nearly free from acids, alkalies, or large quantities of salt. (Concerning the oil-soluble dyes see pages 6 and 7.) The alcohol content of the solution should not exceed 10 per cent. Usually it is better to remove excessive alcohol (by evaporation) than to add water; but if the liquid contains so much sugar as to be sirupy it should be diluted. If the evaporation causes a separation of coloring substance, the sediment should not be removed before the treatment with immiscible solvents. When the color has been extracted directly from solid products by acid amyl alcohol, this may be shaken out with salt solution, dilute hydrochloric acid, or water, as directed for the corresponding solution obtained in the first step of the procedure described on pages 11, 17, and 18.

Since the coloring substances of flowers and fruits are, generally speaking, rather unstable, especially in the presence of alkalies, it is well to divide the solution containing the colors into two portions, one portion to be examined for the natural colors, the other for coal-tar dyes.

TREATMENT OF SOLUTION RESERVED FOR TESTING FOR COAL-TAR DYES.

If coal-tar dyes are not known to be present, a preliminary test may be made by warming a small piece of wool, such as nun's-veiling, or some white woolen yarn with some of the solution; first neutral, then, if no dyeing takes place, made acid with a few drops of hydrochloric acid.[2] If the wool is dyed in either case, the main portion of the solution reserved for dyes is treated as indicated on page 9.

Acid Yellow (sulphonated aminoazobenzene, No. 8) is sometimes more easily separated from mixtures by dyeing on wool than by the use of solvents; hence if the test wool is dyed yellow it may be stripped with dilute ammonia and this solution tested for Acid Yellow by diazotization, etc., as described on page 51.

In the presence of very large amounts of natural coloring matter, it may be advisable occasionally to make the dyeing test with a comparatively large portion of the solution, stripping and redyeing

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[1] For pigments in tea compare Read, U. S. Treasury Decision No. 32322; Knight, J. Ind. Eng. Chem. **6** (1914), 909.

[2] See Strohmer, Z. Anal. Chem. **24** (1885), 625. Arata, Z. Anal. Chem. **28** (1889), 639. Winton, Conn. Agr. Exp. Sta. Rpt. 2 (1889), 131. Sostegni and Carpentieri, Z. Anal. Chem. **35** (1896), 397. Tolman, Jour. Amer. Chem. Soc. **27** (1905). 25.

once or twice if necessary and making a further examination of the color substance obtained from the dyed wool. This procedure is especially advantageous when dealing with cacao products, since such products give extracts containing much natural color similar in tint to the dyes likely to be present, and special care is necessary to avoid overlooking the dyes.

It is desirable to obtain as much information as possible from the dyeing test, since the separation with immiscible solvents can not well be followed with the eye when dealing with dyes of the same shade or with the natural coloring matters, which usually consist of mixtures of substances of similar tint but different solubility.

Attention must be called to the fact that a few rather common dyes are so unstable as to be very easily overlooked when making the dyeing test; for instance, Auramin (No. 425), which is largely used at the present time in European countries for food coloring, is readily decomposed both by acids and alkalies. Naphthol green B also is easily decomposed by acids and not readily dyed on wool from many mixtures. Further, many dyes do not go on wool readily in the presence of certain impurities. In such cases, although getting no positive results by the dyeing test, the analyst should proceed with the separation by immiscible solvents.

GENERAL STATEMENTS REGARDING THE SEPARATION OF DYE MIXTURES.

The analyst usually knows something in regard to the coloring matters present in a dye solution before beginning the systematic analysis. The best procedure to be followed will depend on what dyes are probably present; and no set method can equal in value a table of relative solubilities by means of which the distribution constants of any given dyes may be compared. It is, of course, advantageous in many cases to make group tests with small portions of the mixture, thus avoiding unnecessary and undesirable additions of reagents to the main solution.

In carrying out the fractionations described on pages 11 to 18 any given color will, in general, appear in several washings, but where the maximum amount comes out will be evident from the solubility data; it being always remembered that these statements apply to solutions of concentration in the neighborhood of 0.01 per cent, and that at widely different dilutions some variation may be expected. The solubilities of the components of the dye mixture are not likely to be so different as to allow even a qualitative separation by a single shaking out. It is usually necessary to employ more or less systematic fractionation methods. For example, suppose a mixture is to be separated, of which it is known that one dye, when its amyl alcohol solution is shaken with an equal volume of acid of a certain concentration, distributes itself in equal amount between the two layers, while 94.1 per cent of the other color, under the same conditions, remains in the aqueous layer. If such a mixture in water solution is brought to the given acidity and is shaken out successively with three portions of amyl alcohol, each equal to one-fourth its volume, calculation shows that if the distribution ratios remain constant there will be present in the acid solution after the third shaking twenty-seven sixty-fourths or 42 per cent of the first dye, one sixty-fourth or 1.6 per cent of the second. Conversely the first amyl alcohol portion after two washings with portions of acid of concentration similar to that of the original solution, will contain 42 per cent and 1.6 per cent of the second and first dyes, respectively. Obviously, for a practicable quantitative separation, somewhat greater differences in solubility must exist; but it is usually sufficient to separate, in fairly pure condition, a portion of each of the colors that seem to be present, in order to characterize completely the components of the mixture.[1]

Emulsions occasionally cause trouble when the analyst is working with impure mixtures. These are most effectively broken by a good centrifuge. Should a solid stratum form between the two layers, it should be broken with a glass rod, the tube replaced in the centrifuge and whirled again. Heating tends to promote rapid separation, but the relative solubilities vary somewhat in hot mixtures. Strong acid solutions show much less tendency to emulsify than neutral or alkaline ones.

The final separation of mixtures of dyes of rather similar solubility will usually be made by selecting some pair of solvents in which they show a decided difference. Mixtures of dyes of practically identical solubility can, in most cases, be separated satisfactorily by chemical means or by precipitation reactions. Since the fractionation will have removed all except a few dyes belonging to a known group, suitable chemical methods may usually be chosen without difficulty.

While the scheme described is not intended to be applied to relatively concentrated solutions, in practice in the examination of colored food products, such are seldom or never obtained. The chief concern of the analyst here will be to avoid, as far as possible, the dilution of the color by the use of unnecessarily large portions of organic solvents and washing liquids. Only in working with products sold for use as coloring matters are solutions likely to be made too concentrated to be adapted to the scheme of separation.

As the common food dyes are, for the most part, salts of polybasic acids, the equilibrium conditions are obviously quite complex and concern not only the relative solubilities and dissociation constants of the free color acid, but of the various acid salts and the sodium salt as

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[1] For procedure and calculation as to quantitative fractionations, no coloring matter being rejected, see J. Ind. Eng. Chem. 5 (1913), 26.

well. Many dyes exist in more or less associated condition in ordinary solutions. However, it is found in practice that in most cases the distribution ratios with given acidity do not vary greatly, but that fair results can be obtained on the assumption that they will remain constant.[1]

Both basic and acid triphenylmethane colors tend to undergo slow intermolecular changes when treated with acids and alkalies (adjustment of equilibrium between carbinol, imid, and ammonium forms) and their complete separation by means of solvents is less simple than that of most other classes.

It will be noticed from the solubility table, pages 22–33, that amyl alcohol, amyl alcohol gasoline mixtures, and ether, although differing greatly in their power as solvents, show a sort of general correspondence in properties. They are especially suited for fractionations of such dyes as the sulphonated phenolic compounds, the distribution ratios of these changing greatly with varying hydrogen ion concentrations. Dichlorhydrin, because of its solubility and non-volatility, is not very convenient as a solvent; nevertheless, it is almost indispensable for the separation of many colors. Anilin is an excellent solvent, but usually must be completely removed from a color solution before tests are made, and will be employed only for a few separations. Both anilin and dichlorhydrin are conveniently removed from water solutions by shaking out with carbon tetrachlorid.

It may be remarked that in working with the coal-tar dyes the plan of acidifying strongly, extracting, and then washing the solvent with a more dilute acid, is in nearly all cases preferable to the practice of gradually increasing the acidity and using a number of portions of solvent. Much more solvent is required in this latter way, with a corresponding increase in the proportion of the accompanying impurities and in the difficulties caused by emulsification.

The writer usually prefers to begin the treatment with immiscible solvents by shaking out with amyl alcohol from the neutral solution after addition of some sodium chlorid. The outline which follows will indicate approximately the order in which the solvents will be chosen for a complex mixture.

PROCEDURE OF SEPARATION.

The solution of the coloring matter, as free as possible from suspended matter, is treated carefully with sodium carbonate if it contains free mineral acid or with acetic acid if it is alkaline. It should finally be neutral or very faintly acid. It should not contain the coloring matter in too great concentration, although when working with extracts of food products this latter condition is seldom encountered. Concentrations of about 0.01 per cent may be taken as most suitable in general, and only in exceptional cases would stronger solutions (0.1 per cent, for instance) be chosen by pref-

[1] See W. Reinders and C. Sely, Zeit. für Chem. und Ind. d. Koll. 13 (1913), 96.

erence. In regard to the presence of alcohol, see page 8. When large amounts of dissolved foreign material, such as sugar, glycerol, etc., are present, it must be remembered that the solubilities of the coloring matters will be somewhat affected.

Since almost all coloring matters are found accompanied by small amounts of similarly colored substances of different solubilities (subsidiary dyes, etc.), it should be made an invariable rule in carrying out the separation, first to follow through, to the point of identification, those coloring matters that seem to be present in largest proportion. The course to be pursued in dealing with the smaller fractions will then be more clearly indicated.

Sec. 1.—The solution containing the coloring matter is treated with enough strong sodium chlorid solution to bring the salt concentration to about 5 or 6 per cent and is then shaken out with 20 cc or more of amyl alcohol. If a considerable amount of coloring matter is taken up the extraction is repeated once or twice, the different portions of solvent being finally combined. The amyl alcohol, if colored, is washed once or twice with small portions of 5 per cent salt solution, and these washings, if they appear to contain any dye, are added to the original extracted solution. Any suspended solid matter that may separate may be considered also to belong to the aqueous solution.[1]

The amyl alcohol, if colorless or freed from color by the washing, is discarded. Basic dyes and most of the acid colors of low sulphur content are absent. If the amyl alcohol is colored it is treated as directed in section 10.

Sec. 2.—The extracted salt solution is treated with about one-half its volume of concentrated hydrochloric acid and is again shaken out with amyl alcohol, exactly as described in section 1. Should coloring matter be extracted, the combined portions of the solvent are washed once with diluted acid (1:2, approximately four-normal), then reserved for treatment as stated under section 6. If the alcohol is colorless, and remains so after treatment with an excess of ammonia solution, it is discarded; and most of the strongly sulphonated azo colors are known to be absent. (When Naphthol green B is present, compare section 18.)

Sec. 3.—The extracted acid salt solution which may appear nearly colorless is treated with ammonia until slightly alkaline, then made slightly acid with acetic acid. If it is now colorless the absence of the strongly sulphonated triphenylmethane green and blue dyes is shown, and it is discarded. If it is colored, and if the shade indicates the possible presence of green or blue colors, it is shaken out with dichlorhydrin. This solvent is slightly soluble in water, but an amount should be used so that the lower layer after separation will not measure more than 20 cc. If coloring matter of bluish tint has been extracted, the mixture is again shaken out once or twice, and the combined portions of solvent washed with a little salt solution. The dichlorhydrin solution is then examined according to section 5.

Sec. 4.—The original mixture after the preceding extractions may still contain Acid Magenta, caramel, and many natural colors, especially the glucosids (anthocyans) constituting the common fruit colors. Acid Magenta may be recognized by its reactions with nitrous acid, dyeing properties, etc. It may be separated, if desired, by adding hydrochloric acid so that the acidity is above that of a fourth-normal hydrochloric solution (allowance must be made for the ammonium acetate present) and then shaking out with anilin. The anilin solution is washed with fourth-normal hydrochloric acid in salt solution of from 5 to 6 per cent strength; and the dye then removed with water, perhaps after addition of some carbon tetrachlorid. Before testing this magenta solution the dissolved anilin must be carefully removed, by making alkaline and extracting several times with carbon tetrachlorid, benzene, or other convenient solvent. Commercial Acid Magenta is a somewhat variable mixture of sulphonates and may be expected to yield considerable fractions of lower sulphonated derivatives of greater relative solubility in organic solvents.

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[1] The more systematic procedure described in J. Ind. Eng. Chem. 5 (1913), 26, may be used, if preferred, for this and other similarly described extractions.

The acid yellows (No. 8 and No. 9) although chiefly extracted by amyl alcohol from the acid solution (sec. 2) always yield a large fraction in this group. When the coloration of the extracted acid salt mixture is entirely due to such products it will be orange red, becoming yellow on neutralization, and also will show the characteristic reactions of the acid yellows with nitrous acid, etc.

SEC. 5. The dichlorhydrin solution is diluted with three or four times its volume of carbon tetrachlorid and the color removed with a few small portions of water. The combined washings should be shaken out once with carbon tetrachlorid to get rid of dissolved dichlorhydrin. The aqueous solution may contain the higher sulphonated triphenylmethane colors or perhaps sulphonated indulin. These dyes, like Acid Magenta, are accompanied by large amounts of subsidiary products, and their solubilities can not be established with any definiteness. For their further differentiation compare their properties as shown in the tables.

SEC. 6. The amyl alcohol extract of the strongly acid salt solution, if colored, is washed four or five times with fourth-normal hydrochloric acid, the washings being kept separately. No. 108 and No. 692 predominate in the first washings, while the acidity is still high, because of hydrochloric acid dissolved in the amyl alcohol. No. 106, No. 107, and No. 94 come out in large proportion when the acidity of the lower layer, after the shaking, is below seven-tenths normal (usually about the third washing). Obviously a stronger acid than fourth-normal may be used at first, but it is usually better in practice to wash with this concentration and refractionate if necessary. The dyes that may be present in the acid amyl alcohol extract show a gradual transition in their distribution ratios relative to amyl alcohol (and other like solvents) and hydrochloric acid of varying concentration. Consequently the acid normalities to be chosen in working with an unknown mixture must be selected somewhat according to probabilities.

Comparison of the appearance of the different washings usually will show whether more than one color is present which is extracted by fourth-normal hydrochloric acid in considerable proportion. The amyl alcohol is reserved for the treatment described in section 7 or 8. No. 108 may be separated from Nos. 106, 107, and 94 by fractionation between two-normal hydrochloric acid and amyl alcohol. Nos. 692 and 8 can be separated from Nos. 106, 107, and 94 similarly with eight-normal sulphuric acid and a mixture of equal volumes of amyl alcohol and gasoline; although, since the acid is somewhat difficult to remove afterwards, the procedure is better adapted for separating the last-named dyes in pure condition than Nos. 692 and 8. For Nos. 106, 107, and 94, the amyl alcohol gasoline solution is washed with a little water to take out the dye. This solution is treated with one-half its volume or more of concentrated hydrochloric acid and is reextracted with amyl alcohol. This latter solution may now be washed with a few portions of hydrochloric acid of from four to six normal strength to remove sulphuric acid. The dye is finally removed with a little water and the color obtained in pure condition (for the cyanid reaction, for example) by evaporation to dryness on the steam bath. The dyes in the sulphuric acid solution are best separated by anilin (compare p. 23); but the final removal of this solvent is tedious. No. 94 must be separated from No. 106 and No. 107 by anilin and fourth-normal hydrochloric acid in 5 or 6 per cent salt solution. After the fractionation the dissolved anilin in the solutions must be carefully removed by several extractions with carbon tetrachlorid or other convenient solvent from the faintly alkaline solution.

Commercial No. 692 and No. 8 are made by direct sulphonation of coloring matters and are rather indefinite in composition. It will often be more convenient to divide the solutions of the colors of this group and to destroy different dyes in the various portions. By cautious treatment with "Blankite" ($Na_2S_2O_4$) in acid solution, subsequently shaking with air to restore the blue, No. 692 may be separated from the azo colors.

By reduction in ammoniacal solution, avoiding excess of "Blankite," No. 106 and No. 107 may be destroyed, while No. 8 is merely converted into the hydrazo compound and may be restored by shaking with air. No. 692 is destroyed by warming in acid solution containing a little urea and a drop of sodium nitrite solution, while Nos. 106, 107, and 108 are scarcely attacked. The cyanid reaction is best suited for the examination of mixtures of No. 106 and No. 107.

The dyes of this group, because of their ready solubility in water and fruit juices, are well adapted and largely employed for food coloring. Hence the application of the data given in the solubility table, etc., has been indicated rather more fully here than for the other classes.

Sec. 7. The amyl alcohol extract after being washed with fourth-normal hydrochloric acid may be similarly washed with sixteenth-normal hydrochloric acid; although unless No. 14 or No. 188 appear to be present this step usually will be omitted.

Sec. 8. The amyl alcohol is now measured, diluted with an equal volume of low-boiling-point gasoline, and washed first with fourth-normal hydrochloric acid two or three times, then similarly with sixteenth-normal hydrochloric acid, with sixty-fourth-normal hydrochloric acid, with sixty-fourth-normal acetic acid, and finally with sixty-fourth-normal sodium hydroxid. The dyes separated here include a large number of individuals and the treatment most desirable for any given mixture can best be judged after reference to the tables, pages 24 to 29. Obviously, the normalities stated are chosen somewhat arbitrarily, any two dyes contiguous in the table usually differing little from each other in solubility. When the appearance, etc., of the different fractions indicate the presence of more than one dye, the coloring matters must be obtained in pure condition by refractionation. Although the acid amyl alcohol extract, after dilution with gasoline, appears to yield all its color to the acid washings, it must nevertheless be shaken with the alkaline solution before being discarded, since a number of the weakly acid coloring matters (most of which, it is true, do not properly come in this group) are nearly colorless when dissolved in the neutral or acid organic solvent.

Naphthol yellow S, which predominates in the first strongly acid washings, is also nearly colorless in acid solutions, and a portion from these solutions must always be tested for this dye by making double normal with hydrochloric acid and shaking with washed ethyl acetate. If the separated solvent is found by treatment with alkali to have taken up a yellow dye, the remainder of the fractions containing it are treated in the same way with the acetate. Although the washings of low acidity may contain some coloring matters, the major portion of such dyes will be in the amyl alcohol extract of the neutral salt solution. It is best, therefore, to set aside the sixty-fourth-normal acetic acid and the sixty-fourth-normal sodium hydroxid washings until after the examination of the neutral salt amyl alcohol extract has been made; or these solutions may be mixed with the corresponding ones obtained by the processes outlined in sections 11 and 12 and may be worked up with them. Or, finally, the amyl alcohol gasoline mixture, after washing with sixty-fourth-normal hydrochloric acid, may be reserved and combined with the similar mixture described in section 10.

Sec. 9. For the separation by chemical means of closely similar dyes of these groups some of the more useful general methods may be indicated here.

The reaction with cyanid (page 52) may be used for the separation of R-salt derivatives (Nos. 55, 56, 65, 15) from mixtures with isomers.

Methods based on reduction and subsequent oxidation are applicable for the destruction of azo and nitro colors in presence of most other classes of colors, as indicated in the tables of Weingartner and of Rota.

By cautious reduction in sodium carbonate or ammoniacal solution oxyazo dyes tend to be attacked more rapidly than aminoazo dyes. It must be remembered.

however, that new dyes may also be formed by partial reduction in the case of polyazo or nitroazo derivatives.

The halogenated fluorescein derivatives are much more resistant to bromin in acid solution than are most other colors. They tend, however, to add bromin unless fully substituted. Most of the azo dyes are much more readily destroyed by bromin in alkaline solution than is Naphthol yellow S. Mixtures are made fourth-normal or above with sodium carbonate and are treated with dilute bromin water very cautiously until the azo dye is just destroyed or until the solution has become a clear yellow. Hydrazin sulphate is now added quickly to destroy excess of bromin; the mixture is finally acidified, and the yellow purified by extraction with an immiscible solvent. This procedure is seldom so satisfactory as the regular extraction with ethyl acetate or amyl acetate, and is not applicable in the presence of Nos. 62, 64, 65, and 188, which form intensely blue substances by this treatment.

Sec. 10. The amyl alcohol extract obtained by shaking out the original mixture after adding 5 or 6 per cent salt will contain practically all of any basic dyes present. Most of the acid dyes of low sulphur content are also almost completely extracted. The extract is measured, diluted with an equal volume of gasoline, then washed a few times with sixty-fourth-normal hydrochloric acid. The washings, if colored, are treated as directed in section 11. The extract is next shaken out with sixty-fourth-normal acetic acid, these washings being treated according to section 12. Eosins and (in general) coloring matters that are unsulphonated phenolic compounds are now removed by a few portions of sixty-fourth-normal sodium hydroxid solution, this fraction being treated according to section 13. The amyl alcohol gasoline mixture is finally washed once with very dilute acetic acid and, if still containing any significant amount of coloring matter, is evaporated to dryness on the steam bath, the residue being examined according to section 14.

Sec. 11. The washings of sixty-fourth-normal hydrochloric acid (sec. 10) are tested for basic dyes by making a small portion alkaline with sodium hydroxid, shaking with ether, then treating the ether solution, which is usually colorless, with dilute acetic acid.[1] If the latter becomes colored, indicating the presence of basic dyes, the alkaline test portion may be shaken out once or twice more to determine whether or not acid dyes are also present in this fraction. If these tests indicate the presence of both acid and basic colors, the acid colors must be removed by making the principal part of the sixty-fourth-normal hydrochloric acid extract alkaline (normal with sodium hydroxid) and extracting with ether. From the combined ether portions the basic dyes are removed by washing—first with sixty-fourth-normal acetic acid, finally with dilute hydrochloric acid. This treatment should be omitted if acid dyes are absent, since most basic colors are unstable in alkaline solutions, Auramin, especially, suffering decomposition rapidly. The basic colors may be further fractionated from amyl alcohol with dilute hydrochloric acid, from ether with very dilute alkali, etc. The separation of basic colors from alkaline solutions by immiscible solvents is rather objectionable, since such colors (according to Kehrmann, Havas, and Grandmougin [2]) suffer rearrangement from ortho-quinoid to para-quinoid structure. This change is attended in compounds such as Crystal Violet, containing only fully alkylated amino groups, by elimination of one of the alkyl groups. The original dye may not be obtained therefore, but, instead, the lower alkylated derivative.

The alkaline solution, after removal of the basic dyes with ether, is made about normal with hydrochloric acid and is shaken out with amyl alcohol gasoline mixture. Any coloring matter extracted here probably will be a minor portion of a dye already obtained by the procedure described under section 8, and its further fractionation will be carried out as stated in that paragraph; or the solution containing it may be combined

[1] O. N. Witt, Z. Anal. Chem. **26** (1887), 100. Weingärtner, Z. Anal. Chem. **27** (1888), 232.
[2] Ber. Chem. Ges. **46** (1913), 2131; **47** (1914), 1881.

with the similar solution obtained by the procedure outlined in section 8 and both fractionated together.

The normal hydrochloric acid solution is again partly neutralized by addition of sodium hydroxid (to fourth-normal or less) and is shaken out with a mixture of 3 volumes carbon tetrachlorid and 1 volume dichlorhydrin to extract the lower sulphonated triphenylmethane dyes. These may be obtained in water solution again, by washing out with water after adding more carbon tetrachlorid.

Sec. 12. The acetic acid solution obtained by the procedure described in section 10 will contain the chief part of any monosulphonated monazo dyes present. Such colors may be further fractionated, with amyl alcohol and normal sodium carbonate, with ether and dilute hydrochloric acid, etc.

The coloring matters of this group may appear in small proportion in the fractionation described in section 8, and obviously the similar solutions there described may be combined with the acetic acid solution obtained as described in section 10.

Sec. 13. The main part of the eosin dyes, and of unsulphonated water-soluble acid colors in general, will be found in the sixty-fourth-normal sodium hydroxid solution obtained by the extraction described in section 10. A large proportion of the natural coloring substances also appear here.

The eosin dyes may be fractionated between normal sodium hydroxid and amyl alcohol or amyl alcohol gasoline mixture (3:1).

The acid dyes also having basic tendencies, as Fluorescein (No. 510), Metanil Yellow (No. 95), etc., differ from the others in being extracted from strongly acid solutions in smaller amounts than from weakly acid solutions, and this property offers a suitable means for their separation (pages 27–28). These colors, as already pointed out, may be obtained, though in most cases in very small proportion, in the amyl alcohol gasoline solution obtained by the extraction described in section 8.

Sec. 14.—The residue mentioned in section 10 is moistened with a small drop of alcohol, and then some ether and sixty-fourth-normal hydrochloric acid are added. The mixture is poured into a separatory funnel and is shaken. The aqueous layer is drawn off, and if dyes coloring the aqueous solution were present, the ether is washed a few times further with the sixty-fourth-normal acid, to remove them. The acid solution contains the rhodamins, perhaps also some of the basic azo colors.

The ether solution if colored is now washed a few times with four-normal hydrochloric acid, the washings being neutralized at once and reserved for treatment according to section 15.

The ether is finally washed a few times with water to remove acid; then it is taken to dryness on the steam bath and the residue treated according to section 16.

Sec. 15.—This group, consisting of oil-soluble colors, may be further separated by taking up the dye in gasoline or petroleum ether from the neutralized solution obtained as described in section 14, and fractionating from this solvent with methyl alcohol, 70 per cent or above. (See pages 32–33.) Ortho-tolueneazo-β-naphthylamin suffers decomposition rather rapidly in strongly acid solutions. On the other hand, both it and the lower benzene homologue, when their ether solutions are shaken with acid, are extracted, but slowly, the amount of color removed from the ether depending on the time of contact of the two layers. The substance in the ether layer would thus seem to undergo rearrangement before forming the water-soluble salt, but one or both forms suffer complete decomposition by prolonged standing with the acid.

Sec. 16.—The residue containing Sudans, etc., may be treated with measured quantities of methyl alcohol, water, and sodium hydroxid in the proportions necessary to bring the mixture to fourth-normal alkalinity in 80 per cent alcohol; the solution then may be shaken out with gasoline. Quinolin Yellow and α-naphthol derivatives remain chiefly in the alkaline solvent. The petroleum ether is washed again, if necessary, with the same mixture, then treated as described in section 17.

SEC. 17.—The Sudans and similar dyes of this group may be further separated with gasoline and 90 per cent methyl alcohol. They may be separated from troublesome accompanying oily impurities, by shaking out the gasoline solution with 85 per cent phosphoric acid to which has been added from 10 to 20 per cent of concentrated sulphuric acid, though some dye is likely to be destroyed in this treatment.

Like the colors described in sections 15 and 16, these dyes are almost quantitatively removed from gasoline solution by 90 per cent phenol. The phenol may, of course, be dissolved in alkali and the color again taken up with ether or gasoline, effecting a separation from some impurities.

SEC. 18.—When Naphthol green B is present the salt solution should not be made strongly acid since small amounts of this dye decompose quickly in acid solution. When its presence is suspected, the neutral salt mixture may be first extracted with dichlorhydrin washed once with benzene to remove the dissolved solvent, made half normal with hydrochloric acid, and then shaken out with anilin. (It is best to add the solvent before the acid.) From the anilin solution the dyes may be fractionated by shaking out with 5 or 6 per cent salt solution which contains hydrochloric acid varying from fourth-normal to sixty-fourth-normal.

No outline in the form of a key can be so useful as a table of solubilities. The solvents and the order in which they are to be used obviously may be varied when the analyst has information regarding the source and appearance of a sample. For example, in the case of the red color solution obtained from commercial cocktail cherries known to be ordinarily colored with Erythrosin, it would be better to make such solution acid and shake it out with ether first, the complete extraction of the dye indicating at once the absence of all excepting one group of colors.

In the examination of dye solutions the analyst of some experience often will prefer (especially with colors extracted from acid solutions by amyl alcohol) to wash the organic solvent extract with successive small portions of water instead of with hydrochloric acid or other aqueous solvent of definite concentration. In the case of an acid amyl alcohol extract much hydrochloric acid is taken up by the solvent along with the coloring matter. The acid is washed out rather slowly, and as a result of this gradually decreasing acidity of the washing coloring matters of different solubility will appear in maximum amount in different fractions, the order being apparent from the solubility tables. With binary mixtures usually some of each color is thus obtained pure enough for identification.

The writer prefers, after fractionating the colors into the main groups as just described, to try the bromin test (page 47). The behavior with acids has already been seen in the course of the separation, and that with alkali can be quickly ascertained. Ordinarily these will indicate the fraction to contain but one coloring matter. This is then dyed out from a portion of the solution, and its shade and reactions on the fiber with reagents are compared with standards or with statements in the tables, in which, to facilitate comparison, the dyes have been arranged in the order of their solubility. Since the color changes produced in dilute dye solutions, by addition of acids and alkalies, are closely parallel to those shown by the same reagents on the dyed wool, a single table indicating the reactions on the fiber is sufficient in practice.

Even when the tests have indicated that the fraction still contains a mixture of dyes, they will have shown, in most cases, the absence of many colors of the group, and will have indicated positively which colors are probably present.

ABRIDGED PROCEDURE FOR PERMITTED DYES ONLY.

A convenient abridgment of the fractionation procedure, suitable when it seems probable that only permitted dyes are present, is the following:[1]

The solution or well divided solid matter containing the color is treated with one-half its volume of concentrated hydrochloric acid and is then extracted a few times with amyl alcohol. (For precaution concerning concentration in examining commercial food colors, see page 4.) The alcohol extracts are combined, then washed with four or five portions of fourth-normal hydrochloric acid, or until this solvent extracts very little color. These washings will contain any Indigo Carmine, Tartrazin, and Amaranth which were present in the alcohol solution. Indigo Carmine is removed from the amyl alcohol somewhat more readily than are the other two dyes. With ordinary concentrations little or no Ponceau will be removed.

The amyl alcohol is then measured, if necessary, treated with an equal volume of petroleum ether or low-boiling-point gasoline, and again washed several times with fourth-normal hydrochloric acid to extract Ponceau 3 R and Naphthol yellow S. Or, without dilution with gasoline, it may be washed with 5 per cent salt solution until these two dyes are taken out. After the Ponceau and Yellow have been removed the amyl alcohol, which contains an equal volume of gasoline, is washed a few times with water, thus extracting Orange I. After the removal of this dye the solution, although perhaps appearing almost colorless, is shaken out with a very dilute caustic soda solution to remove Erythrosin.

If considerable Orange I is present, some of it may contaminate the washings containing the Ponceau 3 R and Naphthol yellow S, especially when these have been separated by means of fourth-normal hydrochloric acid after addition of gasoline.

The fourth-normal hydrochloric acid washings of the amyl alcohol may contain Indigo Carmine, Amaranth, and Tartrazin, their appearance in most cases indicating which of these dyes may be present. Instead of attempting to separate the dyes by fractionation the fourth-normal hydrochloric acid solution may be evaporated to dryness,

[1] See also Price, U. S. Dept. Agr., Bur. Anim. Ind. Circ. 180.

the residue dissolved in water, and the constituent colors identified in portions of this solution. A portion of the slightly acidified solution may be warmed, and a few decigrams of urea and then one or two drops of sodium nitrite solution added. Indigo Carmine is converted into the pale yellow Isatinsulphonate, while the other dyes are but little affected. The Isatin compound is not ordinarily present in sufficient concentration to tint the solution, but it differs from Tartrazin also in being much less readily extracted by amyl alcohol from strong acid solution (less than one-half from four-normal acid). Amaranth is much more quickly attacked by most reducing agents than Tartrazin, and may be destroyed in mixtures containing Tartrazin by treating the neutral or faintly acid solution at room temperature with sodium hydrosulphite. (In the presence of sodium carbonate the reduction of Tartrazin takes place still more slowly.) The reagent should be added very carefully, either in dilute solution or as the powder, sufficient time being allowed after each addition for the reduction to take place. When the color shows that the Amaranth has been completely destroyed, the mixture should be shaken at once with air to oxidize the slight excess of hydrosulphite before it can react further on the Tartrazin. To separate the Indigo Carmine another portion of the neutral or faintly acid solution may be heated to boiling and hydrosulphite added very carefully, a few particles at a time, until all the dyes are reduced. On shaking with air the Indigo Carmine is quickly re-formed.

The fourth-normal acid solution (or the salt solution) containing the Ponceau and Naphthol yellow S is treated with enough hydrochloric acid to make it about twice normal, and is shaken out a few times with washed ethyl acetate.[1] The yellow is removed from the combined ethyl acetate extracts by shaking out with water. It must always be remembered that Naphthol yellow S is almost colorless in strongly acid solutions, and its absence in washings, etc., must never be assumed until they have been made alkaline. The Ponceau 3 R is finally separated from the acid solution by shaking the solution with amyl alcohol, then washing out the dye from this extract with a few small portions of water.

When (with mixtures containing Orange I) the washings of the ethyl acetate, which should contain only Naphthol yellow S, become redder with alkalies, they should be combined, made fourth-normal with hydrochloric acid, and the contaminating orange removed by extracting with amyl alcohol gasoline mixture (1:1). Or they may be treated with one-fifth their volume of concentrated hydrochloric acid and the dyes extracted by shaking once with amyl alcohol. From this solution the yellow may be removed by washing with several portions of 5 per cent salt solution.

[1] Used instead of amyl acetate as suggested by Loomis, U. S. Dept. Agr., Bur. Chem. Bul. No. 162, p. 57.

The original mixture, from which the seven colors described were separated by adding acid and shaking out with amyl alcohol, may still contain Light green S F yellowish, which will be colorless or nearly so in the acid solution. To separate this dye the mixture is treated with strong ammonia or potassium hydroxid solution until slightly alkaline, then neutralized with acetic acid. Any green that is present will now be apparent by the color of the mixture and may be extracted by shaking with a few small portions of dichlorhydrin. After washing the dichlorhydrin extract with a little water it should be diluted with several volumes of benzene or carbon tetrachlorid. The dye is then taken out with water.

Besides the well-known reactions of acids and alkalies on the dyed fiber or with the solution, a few tests may be mentioned as best suited for the quick characterization of the different colors obtained in this separation. Indigo Carmine is extracted in rather small proportions from acid aqueous solutions by dichlorhydrin, differing in this respect from nearly all the other common blue dyes. The bromin test (p. 47) and the reactions with acids and alkalies usually are sufficient for the identification of Tartrazin after its separation. New Coccin (No. 106) and Ponceau 6 R (No. 108) are the only other common red dyes of solubility similar to that of Amaranth. Both are yellowish in shade, the former markedly so. Ponceau 3 R, when treated with barium chlorid and enough sodium acetate to neutralize any free hydrochloric acid present, gives a bluish-red flocculent precipitate, the supernatant liquid being left practically colorless. Ponceau 2 R gives a carmine red precipitate; but most other red dyes of similar solubility do not form particularly insoluble barium salts. Naphthol yellow S in solutions treated with an excess of ammonia or sodium carbonate becomes intensely rose colored on addition of sodium hydrosulphite, the color gradually fading again as complete reduction takes place. Orange I is well characterized by its solubility and behavior with acids and alkalies. Erythrosin is perhaps best further identified by a test for iodin. Some of the color solution containing a slight excess of alkali is evaporated to dryness, the residue heated to redness, and the ash taken up with water and acidified with sulphuric acid. Iodin may be tested for in the usual ways, such as with carbon tetrachlorid and a small drop of sodium nitrite, or with starch paste and an oxidizing agent. It is useless to test for iodin with very small amounts of dye, but in most cases sufficient coloring matter will be available to give satisfactory results.

TREATMENT OF SOLUTION RESERVED FOR TESTING FOR NATURAL COLORING SUBSTANCES.

If coal-tar dyes have been found, the treatment for their separation will have given much information as to natural colors that may be present. Many of the natural colors will have been separated in fairly pure condition by the fractionation and the solutions obtained will be ready for identification tests. Obviously, no essential difference exists between these and the so-called coal-tar colors; as a class, however, they show much less tendency to dye wool than do the common synthetic colors, and in addition are in many cases so sensitive to alkalies as to be completely destroyed in the double-dyeing test; i. e., by dyeing, stripping the fiber with dilute ammonia, acidifying, and dyeing again. The preliminary dyeing with wool described on page 8 serves fairly well in practice as a first indication of the course to be followed; but when for some reason the results obtained are not decisive, the general treatment for coal-tar colors with immiscible solvents should be carried out with consideration of solubilities of the coloring matters described in the footnotes in the tables of solubilities. In the dyeing test not only are certain synthetic dyes, especially Auramin, unstable under the conditions of treatment and likely to be destroyed; but, on the other hand, Archil, and to a lesser extent other natural colors, may give well-marked dyeings.

The crude products constituting the commercial natural coloring matters in most cases are mixtures containing several closely related chemical individuals. These may have different solubilities, but usually they contain the same chromophore groups, and are of closely similar shade. In practice, the analyst will scarcely attempt a full separation, but having identified the coloring matter in one fraction, can judge as to the likelihood of the other substances present being derived from the same source.

The natural colors as a class do not contain strongly acidic groups, and their distribution ratios between immiscible solvents do not show wide variations with the acidity of the latter, at least not within convenient limits. The coloring matters of cochineal and turmeric give less trouble than the others, partly because they are less heterogeneous.

When coal-tar dyes are absent, and it is desired to fractionate with immiscible solvents, it is best to begin extraction with neutral solutions; perhaps first using ether (petroleum ether is better when chlorophyll and the accompanying leaf colors are to be separated). The final extraction may be made with amyl alcohol from acid solution, but it is of no advantage to have the acidity high, not, perhaps, above thirty-second normal. The anthocyans which constitute the coloring matters of the common red fruits and flowers are glucosids, and are extracted from acid solution only in very small amount by amyl alcohol and similar solvents. Their neutral solutions may be treated with excess of lead acetate solution (normal salt) when practically all of the glucosid will be precipitated. This mixture may be centrifuged and the precipitate washed in the centrifuge tubes with several portions of water until sugar and similar soluble substances

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents.*

Statements refer in all cases to the amount of dye taken up by the organic solvent when this is shaken with an equal volume of the 0.01 per cent solution of the coloring matter in the various aqueous liquids.

The coloring matters are designated by numbers as given in the tables in "A Systematic Survey of the Organic Coloring Matters." By A. G. Green. Founded on the German of Drs. G. Schultz and P. Julius. Second edition, London and New York, 1904.

For names and references to other large published tables, see page 56.

Numbers denoting permitted dyes are in boldfaced type; natural colors included in the body of the tables are in italics. The numbers of the nonpermitted dyes more commonly found in foods are starred, three stars indicating those dyes most frequently used.

Serial numbers are given in the first column to facilitate reference to the tables of properties, pages 37, 46, 50, and 51.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5-6 per cent) sodium chlorid solution.	Amyl alcohol and hydrochloric acid solutions of varying normality.	Amyl alcohol gasoline mixture (1:1) and dilute hydrochloric acid.	Ether.	Dichlorhydrin and N sodium chlorid solution.	Other data.
1	*462	Crimson; with HCl, little change.	Little or none extracted.	Little or none extracted from acid of concentration 4 N or less.	Little or none extracted from acid of normal concentration or more dilute.	Little or none extracted from acid, neutral, or alkaline solutions.	Little extracted.	
2 3	434 **435**	Green; strongly acid solution, brownish yellow to colorless according to dye concentration.					Larger part or almost all extracted from 5-20 per cent salt solution.	With a mixture of 1 volume washed dichlorhydrin, 3 volumes carbon tetrachlorid, and with N/64 acetic acid: **435**, 439, very little extracted; 491, little extracted; 440, one-half or more extracted.
4	*436	Greenish blue; with HCl, same reaction as **435**.						
5	439	Blue; with HCl, same reaction as **435**.						
6	491	Greenish blue; with HCl, same reaction as **435**.						
7	440	Blue; with HCl, same reaction as **435**.	Less than one-half extracted.					
8	**602	Blackish blue; with HCl, little change.	Little extracted.					
9	**108	Magenta red; with HCl, little change.	Little or none extracted.	4 N, larger part extracted; N, little extracted.			Little or none extracted.	
10	***8	Yellow; with HCl, red.		4 N, larger part extracted; N, one-half or less extracted; N/4 and below, little or none extracted.				With 8 N H_2SO_4 and amyl alcohol gasoline mixture (equal volumes): 8, little extracted; **692**, larger part not extracted; 89, more than one-half extracted; **107**, 106, and **94**, larger part extracted.
11	9	Yellow; with HCl, red.						
12	**89	Yellow; with HCl, red.						
13	**692**	Blue; with HCl, little change.						
14	399	Yellow; with HCl, little change.		4 N, almost all extracted; N, larger part extracted;				With anilin and acid, 5 per cent

15	**106	Scarlet red: with HCl, little change.		N/4 and below, little or none extracted.				sodium chlorid solution (normality stated is that of the HCl before shaking): N/2, **692**, **107**, and **94** almost all extracted; N/4, **94**, less than one-half extracted; 8, 89, **692**, **107**, 106, and 398, almost all extracted; N/16, **94**, little extracted; 89, less than one-half extracted; **602**, about one-half extracted; 106, **107**, more than one-half extracted; 398, chief part extracted; N/64, **107**, 106, **94**, and 398, little or none extracted.
16	107	Magenta red: with HCl, little change.						

Most of the dyes described on these two pages are usually accompanied by considerable amounts of subsidiary products, especially of substances similar chemically but of a different degree of sulphonation

Caramel and the glucosids constituting the coloring matters of most red fruits resemble Acid Magenta (No. 462) in being extracted in small proportion only, by amyl alcohol or dichlorhydrin from the various aqueous solutions.

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents*—Continued.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5-6 per cent) sodium chlorid solution.	Amyl alcohol and hydrochloric acid of varying concentration.	Amyl alcohol gasoline mixture (1:1) and hydrochloric acid of varying normality.	Ether.	Dichlorhydrin-carbon tetrachlorid mixtures (equal volumes; also 1 volume dichlor.+3 volumes CCl_4).	Washed ethyl acetate and 2N hydrochloric acid.
17	**94**	Yellow; with HCl, no change.	Little or none extracted.	As stated for 106 and **107**, p. 23.		Little or none extracted by ether from neutral acid or alkaline solutions.	Little or none extracted by mixture 1:1 or by mixture 1:3, from N/4 HCl or N/64 acetic acid.	Very little or none extracted by ethyl acetate.
18	*398	Green; with HCl, gradually yellow.		Similar to dyes just preceding, but rapidly decomposed.				
19	605	Red; with HCl, little change.		4 N and N; larger part extracted; N/4 less than one-half extracted.				
20	604	Red; with HCl, little change.						
21	188	Violet; with HCl, bluer.		N and above, almost all extracted; N/4, about one-half extracted; N/16 and below, little extracted.	4 N, larger part extracted; N and below, little or none extracted.			
22	***14	Orange; with HCl, no change.						
23	21	Magenta red; with HCl, slightly yellower.		4 N and N, chief part extracted; N/4, more than one-half; N/16, less than one-half.	4 N, larger part not extracted; N, little extracted.			
24	318	Blue; with HCl, little change.		N and above, almost all extracted; N/4, larger part extracted; N/64, less than one-half extracted.	Behaves as stated for 14 and 188.			
25	20	Magenta red; with HCl, no change.			4 N, almost all extracted; N, larger part not extracted; N/16 and below, little or none extracted.			
26	93	Bluish red; with HCl yellower.						
27	***480	Blue; with HCl, slightly paler.			4 N, less than one-half extracted; N and below, little extracted.			

28	*53	Scarlet; with HCl, little change.		N/4 and above, almost all extracted; N/64, one-half or more extracted.	N, one-half or less extracted; N/16 and below, little or none extracted.			
29	*55	Scarlet; with HCl, little change.						
30	105	Scarlet; with HCl, little change.						
31	4	Yellow; with HCl, almost colorless.		The same as above, but large part extracted at N/64.			As stated for 56, 62, etc., p. 27.	Larger part extracted.
32	***706	Orange red; with HCl, little change.						Little extracted.

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents*—Continued.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5–6 per cent) sodium chlorid solution.	Amyl alcohol and hydrochloric acid of varying concentration.	Amyl alcohol gasoline mixture (1:1) and hydrochloric acid of varying concentration.	Ether.	Dichlorhydrin-carbon tetrachlorid mixtures.	Washed ethyl acetate and 2 N hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and dilute sodium hydroxid solution.
33	56	Cherry red; with HCl, no change.	Little or none extracted.	N/16 and above, almost all extracted; N/64, larger part extracted.	N, more than one-half extracted; N/16 and below, little or none extracted.	Little or none extracted from acid, neutral, or alkaline solutions.	Little or none extracted by mixture 3 volumes CCl_4 and 1 volume washed dichlorhydrin, from N/64 acetic acid.	Little extracted.	Little or none extracted from N/64 NaOH solutions.
34	*62	Bluish red; with HCl, little change.							
35	**64	Scarlet, with HCl; slightly darker.							
36	*65	Magenta red; with HCl, little change.							
37	**103	Same reaction as 65.							
38	139	Brown; with HCl, little change.							
39	164	Orange red; with HCl, darker; finally violet.							
40	**667	Yellow; with HCl, no change.							
41	*169	Scarlet; with HCl, darker; finally violet.	Intermediate in behavior between preceding and succeeding groups. Of most of the dyes, more than one-half is extracted.	Almost all extracted at N/64 and above.	N, larger part extracted; N/16, larger part not extracted; N/64, little extracted.				
42	163	Orangered; with HCl, darker.							
43	170	Red; with HCl, darker; finally blue-violet.							
44	84	Orange yellow; with HCl, little change.							
45	146	Cherry red; with HCl, darker; finally blue-violet.							
46	287	Violet; with HCl, little change							
47	78	Red.							
48	***710	Violet.							

The coloring matters described on the lower half of this page are soluble with difficulty in both layers with most acid mixtures. This is especially true of Nos. 78, 710, and 287, which may be precipitated to some extent.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and normal (5-6 per cent) sodium chlorid solution.	Amyl alcohol and dilute hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and dilute hydrochloric acid.	Amyl alcohol gasoline (1:1) and N/64 acetic acid.	Ether and hydrochloric acid of varying concentration.	Dichlorhydrin-carbon tetrachlorid mixture (1:3) and N/64 acetic acid.	Amyl alcohol and N sodium carbonate solution.	Amyl alcohol gasoline mixture (1:1) and N/64 sodium hydroxid.	Ether and dilute sodium hydroxid solution.
49	*546	Orange yellow.	Intermediate in solubility between preceding and succeeding groups.	Almost all extracted at normalities N/64 and above.	As stated for 169, 163, etc., p. 26.			Little extracted.		Little or none extracted.	Little or none extracted by ether from solutions N to N/64.
50	1	Yellow.									
51	307	Violet red.			N, more than one-half extracted; N/16, one-half or less extracted; N/64, larger part not extracted.						
52	328	Yellow.									
53	606	Scarlet.	Chief part extracted.								
54	154	Magenta red.			N/16, one-half or more extracted; N/64 less than one-half extracted.						
55	85	Orange.				Little extracted.			Larger part not extracted.		
56	**13	Orange.	Almost all extracted.		N/16 and above, almost all extracted; N/64, larger part extracted.			Chief part not extracted.			
57	***86	Orange.							Almost all extracted.		
58	97	Orange.									
59	54	Reddish orange.									
60	329	Orange yellow.									
61	137	Brown.				Less than one-half extracted; except 157, more than one-half extracted.		One-half or more extracted.			
62	157	Brownish red.									
63	*95	Orange yellow.					4 N, very little extracted; N, less than one-half extracted; N/64, little extracted.			Less than one-half extracted.	
64	88	Orange yellow.									

The dyes described on this page are rather difficultly soluble with acid mixtures.

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents*—Continued.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5-6 per cent) sodium chlorid solution.	Amyl alcohol and dilute hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and dilute hydrochloric acid.	Amyl alcohol gasoline (1:1) and N/64 acetic acid.	Ether and hydrochloric acid of varying concentration.	Amyl alcohol gasoline mixture (1:1) and N/64 sodium hydroxid solution.	Ether alcohol and N sodium hydroxid solution.	Amyl alcohol and N sodium hydroxid solution.	Amyl alcohol gasoline (3:1) and N sodium hydroxid solution.
65	*92	Yellow.	Almost all extracted.	All or nearly all extracted at N/64 and above.	Almost all extracted at N/64 and above.	Less than one-half extracted.	4 N and N, larger part extracted; N/64, little extracted.	Larger part not extracted.	Little or none extracted by ether, N to N/64.		
66	101	Brown.									
67	102	Red.						Little extracted.			
68	483	Red.	Less than one-half extracted.		Almost all extracted at N/64.	Almost all extracted.	4 N, very little extracted; N, little extracted; N/64, almost all extracted.				
69	**510	Yellow.									
70	26	Orange yellow.	Almost all extracted.		Almost all extracted at N/64 and above.		Almost all extracted at normalities N/64 and above.			Little extracted.	Very little extracted.
71	220	Brownish yellow.								Precipitated.	Precipitated.
72	269	Brownish yellow.									
73	512	Red.	One-half or more extracted by amyl alcohol.							Less than one-half extracted.	Very little extracted.
74	515	Red.									
75	516	Red.									
76	**517**	Red.								Larger part extracted.	Less than one-half extracted.
77	518										
78	520	Bluish red.									One-half or more extracted.
79	521	Bluish red.								Almost all extracted.	
80	*523	Bluish red.	Almost all extracted.								Almost all extracted.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5–6 per cent) sodium chlorid solution.	Amyl alcohol and dilute hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and dilute hydrochloric acid.	Amyl alcohol gasoline mixture and N/64 acetic acid (mixture, 1:1).	Ether and dilute hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and N/64 sodium hydroxid solution.	Ether and dilute sodium hydroxid solution.	Amyl alcohol and normal sodium hydroxid solution.	Amyl alcohol gasoline (3:1) and normal sodium hydroxid solution.
81	2	Orange yellow.	Almost all extracted.	Almost all extracted at normalities 1/64 and above.	Almost all extracted at normalities 1/64 and above.	Almost all extracted.	Almost all extracted at normalities 1/64 and above.	Little extracted (6, larger part not extracted).	Little extracted, N to N/64, except 6; N, almost all extracted; N/64, more than one-half extracted; 3, less than one-half extracted from N.		
82	*3	Yellow.									
83	6	Orange yellow.									
84	534	Alkaline solution, violet.									
85	***707	Alkaline solution, reddish brown.									
86	*10	Alkaline solution, orange.									

Coloring matters of fustic, of quercitron, of Persian berries after hydrolysis, and of alkanet, have similar properties. They are extracted in large proportion by amyl alcohol and by amyl alcohol gasoline mixture (equal volumes) from N/64 acetic acid or from hydrochloric acid, N/64 to N; also by ether from N/64 hydrochloric acid. They are not extracted in large proportion by amyl alcohol gasoline mixture or by ether from N/64 sodium hydroxid solutions. Annatto, not alkali treated, behaves similarly but is extracted in large proportion from N/64 sodium hydroxid by amyl alcohol gasoline mixture (1:1).

Coloring matters of barwood, camwood, and sandalwood resemble Nos. 483 and 510 somewhat in behavior, but are less soluble in aqueous solvents. They are extracted almost completely by amyl alcohol from salt solution, and by amyl alcohol, amyl alcohol gasoline mixture (1:1), and ether from N/64 hydrochloric acid. They are not extracted by amyl alcohol gasoline mixture or ether from N/64 sodium hydroxid. From 4 N hydrochloric acid the chief part of the coloring matter is not extracted by ether; from N hydrochloric acid the chief part is extracted. The coloring matter of brazilwood is similar but relatively somewhat more soluble in aqueous solvents. That of logwood is also similar, but still more soluble in the water solutions. It is almost all extracted by amyl alcohol from salt solution or N/64 hydrochloric acid. The larger part is extracted by amyl alcohol gasoline mixture (equal volumes) from N/64 hydrochloric acid. The chief part is not extracted by ether from N/64 hydrochloric acid and very little from 4 N hydrochloric acid. It is extracted in very small proportion from alkaline solution (N/64 sodium hydroxid) by ether or amyl alcohol gasoline mixture.

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents*—Continued.

No.	Coloring matter.	Color of water solution.	Amyl alcohol and approximately normal (5-6 per cent) sodium chlorid solution.	Amyl alcohol and dilute hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and dilute hydrochloric acid (N/64).	Amyl alcohol gasoline (1:1) and N/64 acetic acid.	Amyl alcohol gasoline (1:1) and N/64 sodium hydroxid.	Ether and dilute acid (N/64 hydrochloric acid or acetic acid).	Ether and N/64 sodium hydroxid.	Dichlorhydrin carbon tetrachlorid mixtures and N/64 acetic acid.
87	*468	Violet.	Nearly all extracted.	4 N, very little extracted.	Little extracted.	Little extracted.	Little extracted.	Little or none extracted.	Little or none extracted.	Almost all extracted by mixture of equal volumes of solvents. By mixture 3 volumes CCl_4, 1 volume $C_3H_6OCl_2$, one-half or more extracted.
88	464	Violet.		N/64, almost all extracted.	More than one-half extracted.	More than one-half extracted.	Chief part extracted.			
89	438	Green.		N/64, almost all extracted.	Larger part not extracted.	Larger part not extracted.	Larger part not extracted.			
90	**433	Green.		Partially extracted.						
91	442	Blue.		Almost all extracted at N/64.						
92	476	Blue.			Some extracted; remainder precipitated.			Little or none extracted; precipitated by HCl.		
93	240	Red.	Extracted from neutral or slightly alkaline solution.	Dye precipitated.	Dye precipitated.	Precipitated.	Not extracted.			
94	277	Brownish red.	Most of dye precipitated.	Most of dye precipitated; rest extracted.						
95	562	Alkaline solution blue to green.								
96	658	Yellow.	Almost all extracted.		Very little extracted.	Very little extracted.		Little or none extracted.		
97	496	Red.								
98	650	Blue.								
99	639	Violet.								
100	*584	Red.								
101	**448	Crimson.								

No.	Coloring matter.	Color of water solution.	Amyl alcohol and normal sodium chlorid solution.	Amyl alcohol and hydrochloric acid of varying concentration.	Amyl alcohol gasoline mixture (1:1) and N/64 hydrochloric acid.	Amyl alcohol gasoline mixture (1:1) and N/64 acetic acid.	Ether and dilute hydrochloric acid N/64 and above.	Ether and dilute acetic acid.	Ether and dilute sodium hydroxid solution.
102 103	***425 426	Yellow. Yellow.	Almost all extracted.		Chief part not extracted.	Little extracted.	Little or none extracted.		Almost all extracted at N/64, but easily decomposed.
104 105	***451 452	Violet. Violet.			Less than one-half extracted.	Chief part not extracted.			N, chief part extracted.
106 107	**427 428	Green. Green.			Chief part not extracted.				
108 109	*197 *201	Brown. Brown.			Very little extracted.	Less than one-half extracted.		N, little extracted; N/64, as below.	Almost all extracted, N to N/64.
110 111	17 18	Orange. Orange.			Chief part not extracted.	More than one-half extracted.		N, larger part, not extracted; N/64, chief part extracted.	
112 113	505 499	Bluish red. Bluish red.			More than one-half extracted.				Almost all extracted at N.
114 115	***504 502	Bluish red. Bluish red.			Chief part extracted.	Almost all extracted.			Almost all extracted, N to N/64.

TABLE 1.—*Extraction of coloring substances from aqueous solutions by immiscible solvents*—Continued.

No.	Coloring matter.		Color of ether solution.	Amyl alcohol and various aqueous solven .	Amyl alcohol gasoline mixture (1:1).	Ether and dilute hydrochloric acid (colors are completely extracted by ether from dilute acetic acid, N to N/64).	Gasoline and methyl alcohol of varying concentration (concentrations are by volume).			
							90 per cent.	80 per cent.	70 per cent.	80 per cent N/4 with sodium hydroxid.
116	**16	Dimethylaminoazobenzene.	Orange yellow.	Oil-soluble colors insoluble in water extracted by amylalcohol from aqueous solvents almost completely.	Extracted from water, N/64 acetic, or N/64 HCl.	4 N, very little extracted; N/64, almost all extracted.	Larger part not extracted.	Less than one-half extracted.	Almost all extracted.	About one-half extracted.
117	7	Aminoazobenzene.	Orange yellow.				Very little extracted.	Very little extracted.	Very little extracted.	Very little extracted.
118	*	Aminoazo-o-toluene.	Orange yellow.			4 N, less than one-half extracted; N/64, almost all extracted.	Little extracted.	Chief part not extracted.	Larger part not extracted.	Chief part not extracted.
119		Benzeneazo-β-naphthylamin.	Orange yellow.			4 N, much extracted: N/64, almost all extracted; colors undergo slow rearrangement in acid solvents.				
120		Ortho-tolueneazo-β-naphthylamin.	Orange yellow.							
121	666	Quinophthalon.	Yellow.			4 N, almost all extracted; N/64, extracted.	Little extracted.	Chief part not extracted.	Chief part not extracted.	Very little extracted.
122		Benzeneazo-α-naphthol.	Brown.				Very little extracted.	Very little extracted.	Very little extracted.	
123	59	α-Naphthaleneazo-α-naphthol.	Brown.			....	Chief part not extracted.	Larger part extracted.	Larger part extracted.	
124		Ortho-tolueneazo-o-tolueneazo-α-naphthol.	Brownish red.			Practically all extracted, 4 N and below.	Chief part extracted.	Almost all extracted.	Almost all extracted.	Little extracted.
125	*11	Benzeneazo-β-naphthol.	Orange.				Chief part extracted.			
126	**49	Meta-xyleneazo-β-naphthol.	Orange red.							Chief part extracted.
127	60	α-Naphthaleneazo-β-naphthol.	Red.							Almost all extracted.

128	*143	Benzeneazobenzeneazo-β-naphthol.	Red.							
129	*	Ortho-tolueneazo-o-tolueneazo-β-naphthol.	Red.							
130	31	Para-nitrobenzeneazo-β-naphthol.	Orange.				Chief part not extracted.	Chief part extracted.		Little extracted.

Ortho-tolueneazo-β-naphthylamin is rather rapidly destroyed in strongly acid solutions.

have been removed. The precipitate may then be dissolved in hydrochloric acid of 10 or 15 per cent strength. After whirling again in the centrifuge to separate the lead chlorid thrown out of the solution, the clear red liquid is shaken out once or twice with amyl alcohol to remove various extractives soluble in this substance. It may then be boiled for a short time, by which means the glucosid is hydrolyzed, the derived coloring matter, or anthocyanidin, being produced. This may now be extracted and obtained in fairly pure solution by shaking out with amyl alcohol. The anthocyanidins, according to Willstaetter,[1] are oxonium bases, containing also acidic phenolic groups. They are not very readily soluble in amyl alcohol though relatively more so than in aqueous liquids.

The coloring principles of saffron and of Persian berries also consist chiefly of glucosids, though the lead salts of these are relatively more soluble. These glucosids also are readily hydrolyzed by boiling with acid, but the change in case of saffron is attended with destruction of much coloring matter, at least when the hydrolysis is carried out in the ordinary manner, with free access of air. Berberine is said to be the only common natural basic coloring matter and it is seldom, if ever, found in food products.

By extraction from neutral solutions with ether, the leaf pigments (identical or similar colors are also found in egg yolk,[2] fats and oils,[3] carrots, and tomatoes[4]) are taken up. They are removed from this solvent by washing with dilute alkali.

Coloring matters of alkanet, annatto, turmeric, and of the red dyewoods (sandalwood, camwood, and barwood) are very readily and completely extracted by ether from slightly acid solutions. The flavone coloring matters of fustic, of Persian berries (after hydrolysis), and of quercitron, also the coloring matter of brazilwood and the green derivatives formed from chlorophyll by alkali treatment, are taken up in very large proportion by ether from slightly acid solutions.

The coloring matters of logwood, of archil, of saffron, and of cochineal are extracted in relatively small amount by ether from slightly acid solutions, but are largely taken up by amyl alcohol.

Caramel and the anthocyans constituting the red coloring matters of most common fruits are extracted in relatively small proportion by amyl alcohol from acid solutions. Ammoniacal cochineal (carmine) is similar, but the ordinary coloring matter is readily re-formed by standing with hydrochloric acid.

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[1] Sitzb. kgl. Preuss. Acad. 12 (1914), 402–411. For further papers by Willstaetter and coworkers see Liebig's Ann. 408 (1915), 1-158.

[2] Willstaetter and Escher, Zeit. Physiol. Chem. **76**, (1912), 214.

[3] See Palmer and Eckles, Mo. Sta. Research Bul., Nos. 9, 10, 11, 12.

[4] Willstaetter and Stoll, Untersuchungen ueber Chlorophyll, Berlin (1913).

IDENTIFICATION OF COLORING SUBSTANCES.

COAL-TAR DYES.

The coloring matters are usually obtained by the fractionation dissolved in various aqueous or organic solvents, but free from non-volatile substances. Neutral solutions suitable for certain tests are most easily obtained by evaporating to dryness and taking up the residue with water or other suitable solvent.

It is not intended to discuss here the innumerable tests that may be used for the individual dyes. There are described a limited number only of general procedures which are quickly and easily carried out, and the chemistry of which is for the most part understood. These tests are sufficient for identification in ordinary cases.[1]

For ready comparision of colors of similar solubility, it is convenient to have tables of properties in which the arrangement is based on the solubility. The familiar reactions of reduction and of color changes with reagents applied to the dyed fiber are given in this order in Tables 2 and 3, these tests being made as follows:

Reactions on dyed fiber.[2]—Small pieces or shreds of the dyed wool are distributed on the porcelain plate and are thoroughly moistened with the reagents. The fiber must be dry or nearly so, and must have been dyed in a fairly pure solution of the color, since colorless organic impurities may easily obscure the reaction.

Reduction and subsequent reoxidation.[3]—The neutral color solution is treated with a few particles of powdered sodium hydrosulphite, conveniently dropped in from a small spatula. If no color change is seen at once, the mixture is warmed somewhat and more reagent added, carefully avoiding excess, however. If reduction, shown by disappearance of the color, takes place, the solution is thoroughly shaken with air, and should this not bring back the dye, it is warmed and allowed to stand a few minutes. Finally, if remaining practically colorless, a little powdered potassium persulphate is dropped in. A slight yellowish or brownish tint produced by air or especially by the potassium persulphate is disregarded.

In regard to the tests on the dyed wool, it may be said that the dyeings obtained from colors in food products are necessarily variable in depth and usually paler than those used as a basis for standards. With the very small amounts of color available, it is impossible to

[1] For the identification of the simpler azo dyes by reduction, separation of the reduction products and characterization of these by coupling with diazo compounds, by condensation with nitrosodimethylanilin, and by diazotization, see especially Witt, Ber. Chem. Ges. **19** (1886), 1719, and **21** (1888), 3468. Properties of the various amins, aminophenols, and their sulphonic acids are summarized by Heumann (Friedländer, Schultz), Die Anilinfarben. Braunschweig, 1888-1906.

[2] The tables are made to correspond as nearly as possible with those of U. S. Dept. Agr., Bur. Chem. Cir. No. 63, 0.5 per cent dyeings and reagents of similar concentration being used.

[3] Hydrosulphite and persulphate are the reagents advocated by Green, Yeoman, and Jones, J. Soc. Dyers & Colorists **9** (1905), 236; also Green, Identification of Dye Stuffs, Leeds (1913).

make dyeings to any convenient standard depth, and descriptions can only indicate in a general way what may be expected. Not only will the appearance of the dyed wool under the influence of different reagents vary somewhat with the concentration of the dye present, but the shade of the dry fiber also may vary with the concentration of the dye. For example, dyeings from some of the oranges are almost yellow when only a little color is present, but are a much redder shade when more dye is used.

Color changes similar to those taking place on dyed fibers are produced in most cases by the given reagents in solutions of the dyes, and the conditions are under much more exact control. So in some cases it is advantageous to compare the solution of the dye under examination with solutions of known colors, all being brought as nearly as possible to the same dye concentration, and to the same acid or alkali normality. An exact statement of shade can be given best by spectrophotometric data (according to Vierort's method) under prescribed conditions of temperature and concentration. This is desirable in some cases, as when dealing with mixtures of Ponceau 2 R and Ponceau 3 R. For the somewhat related and more rapid spectroscopic method of measuring the spectral position of maximum light absorption in dilute solutions, the treatises of Formanek, of Formanek and Grandmougin, and of Mulliken may be consulted. However, the "spot reactions," if not of the greatest exactness, are sufficiently exact for most purposes, and are especially convenient in inspection work, where it is well to keep a specimen of the color dyed on cloth.

TABLE 2.—*Behavior of dry colors or of dyed fibers with reagents.*

[Numbers denoting permitted dyes are in boldfaced type; natural colors are in italics. Dyes common in foods are starred, three stars indicating those dyes most often found.]

No.	Coloring matter.	Color of sulphuric acid solution.	Color of dyed wool.	Reactions of dyed wool with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
1	***462	Yellow.	Violet red.	Nearly decolorized.	Yellow	Decolorized.	Decolorized.
2	434	Yellow.	Green.	Yellow.	Orange or pale brown.	Decolorized.	Decolorized.
3	**435**	Yellow.	Green.	Yellow.	Orange or pale brown.	Decolorized.	Decolorized.
4	*436	Yellow.	Greenish blue.	Yellow.	Orange or pale brown.	Little change (slightly darker).	Little change (slightly darker).
5	439	Yellow.	Greenish blue.	Yellow.	Orange or pale brown.	Yellow olive.	Redder.
6	491	Yellow.	Green.	Yellow.	Orange or pale brown.	Little change.	Little change.
7	440	Yellow.	Greenish blue.	Yellow.	Orange or pale brown.	Little change.	Little change.
8	**602	Deep blue.	Bluish gray to black.	Dull bluish	Dull greenish.	Pale brownish red.	Pale reddish.
9	**108	Violet.	Red.	Bluish red.	Violet.	Brown.	Orange red.
10	***8	Brownish yellow.	Yellow.	Red.	Orange.	Little change.	No change.
11	9	Brownish yellow.	Yellow.	Red.	Orange.	Little change.	No change.
12	**89	Violet red.	Yellow.	Bluish red.	Bluish red.	Little change.	Little change.
13	**692**	Violet blue.	Blue	Slightly darker.	Slightly darker.	Greenish yellow.	Greenish blue.
14	399	Reddish brown.	Orange yellow.	Yellowish, dull.	Reddish brown.	Orange.	Orange.
15	***106	Red violet.	Scarlet.	Red.	Violet red.	Yellowish brown.	Orange red.
16	**107**	Violet.	Red.	Slightly darker.	Violet to brownish.	Dull brownish.	Little change.

TABLE 2.—*Behavior of dry colors or of dyed fibers with reagents*—Continued.

No.	Coloring matter.	Color of sulphuric acid solution.	Color of dyed wool.	Reactions of dyed wool with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
17	94	Yellow.	Yellow.	Slightly darker.	Slightly darker.	Little change.	Little change.
18	*398	Yellowish brown.	Yellowish green.	Yellowish.	Brownish yellow.	No change.	No change.
19	605	Green.	Red.	Little change.	Dark green.	Little change.	Little change.
20	604	Green.	Red.	Dull brown.	Dark green.	Little change.	Little change.
21	188	Greenish black.	Bluish black.	Greenish blue.	Olive green.	Black.	No change.
22	***14	Orange yellow.	Orange yellow.	Little change.	Orange.	Dull brownish red.	No change.
23	21	Red.	Violet red.	Orange red.	Brownish red.	Brownish red.	Little change.
24	318	Bluish green.	Blue.	Little change.	Greenish blue.	Red.	Redder.
25	20	Red.	Red.	Little change.	Darker.	Reddish brown.	Brown.
26	93	Violet.	Violet red.	Little change.	Violet.	Slightly bluer.	Orange red.
27	***480	Brown.	Blue.	Paler.	Brown.	Pale reddish.	Almost decolorized.
28	*53	Violet red.	Scarlet.	Darker.	Violet red.	Brownish yellow.	No change.
29	*55	Red.	Scarlet.	Little change.	Little change.	Brownish yellow.	No change.
30	105	Violet.	Red.	Slightly bluer.	Reddish violet.	Dull brownish red.	Almost unchanged.
31	4	Pale yellow.	Yellow.	Nearly decolorized.	Very pale dull brown.	No change.	No change.
32	***706	Red orange.	Dull orange red.	Little change.	Little change.	Violet red.	Violet red.

33	56	Red.	Red.	Little change.	Little change.	Dull orange.	Little change.
34	*62	Blue.	Violet red.	Darker.	Violet.	Dull brown.	Little change.
35	**64	Violet.	Scarlet.	Violet red.	Violet.	Dull brown.	Little change.
36	*65	Blue.	Violet red.	Violet.	Blue.	Brown.	Little change.
37	**103	Violet.	Violet red.	Little change.	Violet.	Scarlet.	Scarlet.
38	139	Violet.	Brown.		Dark violet.	Darker.	Little change.
39	164	Blue.	Scarlet.				
40	**667	Orange red.	Yellow.	Slightly darker.	Brownish yellow.	Slightly paler.	Little change.
41	*169	Blue.	Red.	Blue.	Blue.	Dull violet red.	Little change.
42	163	Green.	Red.	Violet blue.	Green.	Dull violet.	Little change.
43	170	Blue.	Red.				
44	84	Yellow.	Orange yellow.	Orange.	Orange.	Dull orange red.	No change.
45	146	Reddish violet.	Red.	Blue.	Violet.	Brown.	No change.
46	287	Deep blue.	Reddish blue.	Darker.	Greenish blue.	Red.	Violet.
47	78	Violet red.	Red.	Brown.	Violet red.	Little change.	Little change.
48	***710	Violet.	Red.	Red.	Brown, dull.	Violet.	Violet.

TABLE 2.—*Behavior of dry colors or of dyed fibers with reagents*—Continued.

No.	Coloring matter.	Color of sulphuric acid solution	Color of dyed wool.	Reactions of dyed wool with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
49	*546	Orange.	Orange yellow.	Yellow.	Orange.	Violet.	Violet.
50	1	Almost colorless.	Yellow.	Decolorized.	Pale brownish.	Little change (slightly darker).	No change.
51	507	Orange.	Reddish violet.	Slightly yellower.	Orange.	Red.	Red.
52	328	Reddish violet.	Orange yellow.	Dull violet.	Brownish violet.	Orange red.	Orange red.
53	606	Dull green.	Orange.	Yellowish brown.	Dark green.	Little change.	Little change.
54	154	Violet blue.	Red.	Blue.	Blue.	Brownish violet.	Little change.
55	**85**	Violet.	Orange.	Violet.	Violet.	Red, dark.	Red, dark.
56	**13	Orange yellow.	Orange.	Orange red.	Orange.	Slightly darker.	No change.
57	***86	Red.	Orange.	Red.	Red.	Dull orange red.	No change.
58	97	Red.	Orange.	Red.	Red.	Browner.	Browner.
59	54	Orange red.	Orange.	Scarlet.	Scarlet.	Little change.	No change.
60	329	Reddish violet.	Yellow.	Blue.	Reddish violet.	Orange yellow.	No change.
61	137	Brown.	Brown.		Darker.	Darker.	
62	157	Bluish green.	Red.	Blue violet.	Green.	Brownish violet.	Little change.
63	*95	Violet.	Orange yellow.	Violet red.	Violet.	No change.	No change.
64	88	Violet.	Orange yellow.	Violet red.	Violet.	No change.	No change.

65	*92	Violet red.	Yellow.	Violet red.	Violet red.	Dull brown.	Little change.
66	101	Blue.	Brown.	Reddish blue.	Blue.	Violet red.	Violet red.
67	102	Violet.	Red.	Red.	Violet.	Dull orange red.	No change.
68	483	Brownish yellow.	Orange red.	Orange yellow.	Dull orange yellow.	Little change.	Little change.
69	**510	Yellow.	Yellow.	Little change.	Little change.	Slightly redder, green fluor.	Little change, green fluor.
70	26	Orange yellow.	Orange yellow.	Orange.	Orange.	Orange red.	Orange.
71	220	Reddish violet.	Yellow.	Brown.	Violet red.	Red orange.	Orange yellow.
72	269	Reddish violet.	Yellow.	Brown.	Violet red.	Red orange.	Orange yellow.
73	512	Yellow.	Red.	Yellow orange.	Yellow orange.	No change.	No change.
74	515	Brownish yellow.	Violet red.	Yellow.	Brownish.	Scarlet.	Little change.
75	516	Brownish yellow.	Orange red.	Orange yellow.	Orange yellow.	No change.	No change.
76	517	Brownish yellow.	Violet red.	Orange yellow.	Orange yellow.	No change.	No change.
77	518	Brownish yellow.	Violet red.	Yellow.	Orange.	No change.	No change.
78	520	Orange.	Violet red.	Yellowish.	Orange.	No change.	No change.
79	521	Orange.	Violet red.	Yellowish.	Orange.	No change.	No change.
80	*523	Orange.	Red violet.	Almost decolorized.	Orange.	No change.	No change.

TABLE 2.—*Behavior of dry colors or of dyed fibers with reagents*—Continued.

No.	Coloring matter.	Color of sulphuric acid solution.	Color of dyed wool.	Reactions of dyed wool with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
81	2	Pale yellow.	Orange yellow.	Almost decolorized.	Pale brownish yellow.	No change.	No change.
82	*3	Pale yellow.	Yellow.	Almost decolorized.	Pale brownish yellow.	Little change.	Little change.
83	6	Very pale yellow.	Orange.	Almost decolorized.	Pale brownish yellow.	Dull orange red.	Slightly redder.
84	*534*	Orange red.	Orange.	Yellower.	Redder.	Violet.	Violet.
85	****707*	Orange.	Yellow.	Red.	Reddish brown.	Orange.	Orange.
86	*10	Yellowish orange.	(Silk.) Orange yellow.	(Silk.) Orange yellow.	(Silk.) Brownish yellow.	(Silk.) Orange yellow.	(Silk.) No change.

87	*468	Orange yellow.	Violet.	Pale orange yellow.	Pale dull orange.	Decolorized.	Decolorized.
88	464	Yellow.	Bluish violet.	Pale orange yellow.	Pale dull orange.	Decolorized.	Decolorized.
89	438	Yellowish brown.	Green.	Orange yellow.	Brownish yellow.	Decolorized.	Paler.
90	**433	Yellow.	Green.	Pale orange yellow.	Pale dull yellow.	Decolorized.	Decolorized.
91	442	Yellow.	Greenish blue.	Pale orange yellow.	Pale dull yellow.	Little change.	Little change.
92	476	Reddish brown.	Blue.	Little change.	Reddish brown.	Dull brown.	Little change.
93	240	Blue.	Reddish brown.	Blue.	Blue.	No change.	No change.
94	277	Blue.	Brownish red.	Blue.	Greenish blue.	Orange red.	Orange red.
95	562	Brownish red.	Violet blue.	Orange red.	Brownish red.	Green.	Blue.
96	658	Colorless.	Yellow.	Decolorized.	Almost decolorized.	Decolorized.	Paler.
97	496	Orange.	Red.	Orange yellow.	Yellow.	Paler.	Paler.
98	650	Yellowish green.	Blue.	Almost decolorized.	Greenish, paler.	Pale violet.	No change.
99	639	Dark green.	Blue.	Violet blue.	Dull greenish.	Pale dull violet red.	Pale dull violet red.
100	*584	Green.	Red.	Greenish blue.	Green.	Red.	Red.
101	**418	Yellowish brown.	Violet red.	Yellowish brown.	Dull brown.	Decolorized.	Paler.

TABLE 2—*Behavior of dry colors or of dyed fibers with reagents*—Continued.

No.	Coloring matter.	Color of sulphuric acid solution.	Color of dyed wool.	Reactions of dyed wool with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
102	***425	Colorless.	Yellow.	Decolorized.	Nearly decolorized.	Decolorized.	Paler.
103	426	Colorless.	Yellow.	Decolorized.	Nearly decolorized.	Decolorized.	Paler.
104	***451	Yellow.	Violet.	Yellowish.	Yellowish.	Decolorized.	Almost decolorized.
105	452	Yellow.	Violet.	Yellowish.	Yellowish.	Decolorized.	Almost decolorized.
106	**427	Yellow.	Bluish green.	Almost decolorized.	Almost decolorized.	Decolorized.	Decolorized.
107	428	Yellow.	Green.	Almost decolorized.	Almost decolorized.	Decolorized.	Decolorized.
108	*197	Brown.	Reddish brown.	Redder, darker.	Browner.	Yellower.	Yellower.
109	201	Brown.	Reddish brown.	Redder, darker.	Browner.	Yellower.	Yellower.
110	17	Orange yellow.	Orange yellow.	Orange red.	Brownish red.	Slightly duller.	Yellower.
111	18	Orange yellow.	Orange yellow.	Red.	Brown.	Slightly duller.	Yellower.
112	505	Yellow.	Violet red.	Orange.	Yellow.	Slightly bluer.	Slightly bluer.
113	499	Yellow.	Bluish red.	Orange.	Yellow, pale.	Slightly bluor.	Slightly bluer.
114	***594	Yellowish brown.	Bluish red.	Orange.	Yellow.	Bluer.	Bluer.
115	502	Yellowish brown.	Bluish red.	Orange.	Yellow.	Slightly bluer.	Slightly bluer.

No.	Coloring matter.	Color of sulphuric acid solution.	Color of dyed silk.	Reactions of dyed silk with reagents.			
				Concentrated hydrochloric acid.	Concentrated sulphuric acid.	10 per cent sodium hydroxid solution.	Ammonia solution, specific gravity, 0.95.
116	**16. Dimethylaminoazobenzene.	Yellow.	Orange yellow.	Red, bluish.	Orange yellow.	No change.	No change.
117	7. Aminoazobenzene.	Yellow.	Orange yellow.	Brownish red.	Orange yellow.	Little change.	No change.
118	*. Ortho-aminoazotoluene.	Orange yellow.	Orange yellow.	Dull orange.	Orange yellow.	Little change.	No change.
119	Benzeneazo-β-naphthylamin.	Reddish violet.	Yellowish brown.	Red.	Violet.	Little change.	No change.
120	Ortho-tolueneazo-β-naphthylamin.	Violet.	Yellowish brown.	Red.	Violet.	Little change.	No change.
121	666. Quinophthalon.	Reddish brown.	Yellow.	Orange yellow.	Brownish yellow.	Orange yellow.	Little change.
122	Benzeneazo-α-naphthol.	Violet.	Orange.	Violet red.	Violet.	Deep red.	Deep red.
123	59. Naphthaleneazo-α-naphthol.	Greenish blue.	Brown.	Bluish violet.	Greenish blue.	Bluish red.	Bluish red.
124	Ortho-tolueneazo-α-toluene	Green.	Red.	Blue.	Green.	Reddish blue.	Reddish blue.
125	*11. Benzeneazo-β-naphthol.	Red.	Orange.	Orange red.	Red.	Redder.	Little change.
126	**49. Meta-xyleneazo-β-naphthol.	Violet red.	Orange red.	Red.	Violet red.	Little change.	No change.
127	60. α Naphthaleneazo-β-napthhol	Bluish violet.	Bluish red.	Slightly bluer.	Dull blue.	Browner and paler.	Slightly paler.
128	*143. Benzeneazobenzeneazo-β-naphthol.	Green.	Red.	Violet, then brown.	Green.	Violet red.	Little change.
129	*. Ortho-tolueneazo-o-tolueneazo-β-naphthol.	Green.	Violet red.	Violet blue.	Bluish green.	Violet red.	Little change.
130	31. Para-nitrobenzeneazo-β-naphthol.	Violet red.	Brownish red.	Orange red.	Violet red.	Violet blue.	No change.

With concentrated solution of stannous chlorid in hydrochloric acid the fiber is decolorized in all cases except that of No. 666.

TABLE 3.—*Behavior of colors when treated with reducing agents followed by oxidizing agents.*

[Numbers denoting permitted dyes are in boldfaced type; natural colors are in italics. Dyes common in foods are starred, three stars indicating those most often found. Statements apply in general to 0.01 per cent solutions.]

No.	Coloring matter.	With sodium hydrosulphite.	Coloring matter.	Reduction product with air or potassium persulphate.
1	*462	Almost decolorized.	*462	Color restored.
2	434	Almost decolorized.	434	Color partially restored.
3	**435**	Almost decolorized.	**435**	Color partially restored.
4	*436	Becomes paler very slowly.	*436	
5	439	Paler, slowly.	439	Color restored.
6	491	Almost decolorized.	491	Some color returns.
7	440	Decolorized.	440	Color restored.
8	**602	Pale olive.	**602	Color restored.
9	**108	Decolorized.	**108	Remains colorless or nearly so.
10	***8	Decolorized.	***8	Remains colorless or nearly so.
11	9	Decolorized.	9	Remains colorless or nearly so.
12	**89	Decolorized.	**89	Remains colorless or nearly so.
13	**692**	Decolorized.	**692**	Color restored.
14	399	Not decolorized.	399	
15	***106	Decolorized.	***106	Remains colorless or nearly so.
16	**107**	Decolorized.	**107**	Remains colorless or nearly so.
17	**94**	Decolorized.	**94**	Remains colorless or nearly so.
18	*398	Decolorized.	*398	Remains colorless or nearly so.
19	605	Pale orange.	605	Color restored.
20	604	Pale orange.	604	Color restored.
21	198	Decolorized.	198	Remains colorless or nearly so.
22	***14	Decolorized.	***14	Remains colorless or nearly so.
23	21	Decolorized rather slowly.	21	Remains colorless or pale brownish.
24	318	Bluer; then decolorized.	318	Remains colorless or nearly so.
25	20	Decolorized.	20	Remains colorless or nearly so.
26	93	Decolorized.	93	Remains colorless or nearly so.
27	***480	Much paler.	***480	Color restored.
28	*53	Decolorized.	*53	Remains colorless or nearly so.
29	*55	Decolorized.	*55	Remains colorless or nearly so.
30	105	Decolorized.	105	Remains colorless or nearly so.
31	**4**	Decolorized.	**4**	Remains colorless or nearly so.
32	****706*	Not decolorized.	****706*	
33	**56**	Decolorized.	**56**	Remains colorless or nearly so.
34	*62	Decolorized.	*62	Remains colorless or nearly so.
35	**64	Decolorized.	**64	Remains colorless or nearly so.
36	*65	Decolorized.	*65	Remains colorless or nearly so.
37	**103	Decolorized.	**103	Remains colorless or nearly so.
38	139	Decolorized.	139	Remains colorless or nearly so.
39	164	Decolorized.	164	Remains colorless or nearly so.
40	**667	Not changed.	**667	
41	*169	Bluer; then decolorized.	*169	Remains colorless or nearly so.
42	163	Decolorized.	163	Remains colorless or nearly so.
43	170	Bluer; then decolorized.	170	Remains colorless or nearly so.
44	84	Decolorized.	84	Remains colorless or nearly so.
45	146	Bluer; then decolorized.	146	Remains colorless or nearly so.
46	287	Slowly decolorized.	287	Remains colorless or nearly so.
47	78	Slowly decolorized.	78	Remains colorless or nearly so.
48	****710*	Decolorized, nearly.	****710*	Color restored.
49	*546	Not changed.	*546	
50	**1**	Decolorized.	1	Not restored.
51	507	Not changed.	507	
52	328	Decolorized.	328	Remains colorless or nearly so.
53	606	Pale yellow.	606	Color restored.
54	154	Bluer; then decolorized.	154	Remains colorless or nearly so.
55	**85**	Decolorized.	**85**	Remains colorless or nearly so.
56	**13	Decolorized.	**13	Remains colorless or nearly so.
57	***86	Decolorized.	***86	Remains colorless or nearly so.
58	97	Decolorized.	97	Remains colorless or nearly so.
59	54	Decolorized.	54	Remains colorless or nearly so.
60	329	Decolorized.	329	Remains colorless or nearly so.
61	139	Decolorized.	139	Remains colorless or nearly so.
62	157	Decolorized.	157	Remains colorless or nearly so.
63	*95	Decolorized.	*95	Colorless or slightly yellow.
64	88	Decolorized.	88	Colorless or slightly yellow.
65	*92	Decolorized.	*92	Remains colorless or nearly so.
66	101	Decolorized.	101	Remains colorless or nearly so.
67	102	Decolorized.	102	Remains colorless or nearly so.
68	483	Decolorized.	483	Color restored.
69	*510	Much paler.	*510	Color restored.
70	26	Decolorized.	26	Remains colorless or nearly so.
71	220	Decolorized.	220	Remains colorless or nearly so.
72	269	Decolorized.	269	Remains colorless or nearly so.
73	512	Much paler (with excess).	512	Color restored.
74	515	Much paler (with excess).	515	Color restored.
75	516	Much paler (with excess).	516	Color restored.

TABLE 3.—*Behavior of colors when treated with reducing agents followed by oxidizing agents*—Continued.

No.	Coloring matter.	With sodium hydrosulphite.	Coloring matter.	Reduction product with air or potassium persulphate.
76	517	Much paler (with excess).	517	Color restored.
77	518	Much paler (with excess).	518	Color restored.
78	520	Much paler (with excess).	520	Color restored.
79	521	Much paler (with excess).	521	Color restored.
80	*523	Much paler (with excess).	*523	Color restored.
81	2	Decolorized.	2	Remains colorless or nearly so.
82	*3	Decolorized.	*3	Remains colorless or nearly so.
83	6	Dark; then pale.	6	Pale reddish.
84	*534*	(Alk. sol.), red, slowly.	*534*	Color restored.
85	***707	Not reduced.	***707	
86	*10	Decolorized.	*10	Remains colorless or nearly so.
87	*468	Decolorized.	*468	Color restored.
88	464	Decolorized.	464	Color restored.
89	438	Almost decolorized.	438	Color restored.
90	**433	Paler.	**433	Greener.
91	442	Paler, slowly.	442	Restored.
92	476	Not readily reduced.	476	
93	240	Almost decolorized.	240	Remains colorless or nearly so.
94	277	Browner; then colorless.	277	Remains colorless or nearly so.
95	562	(Alk. sol.), yellow.	562	Color restored.
96	658	No change.	658	
97	496	Almost decolorized.	496	Color largely restored.
98	650	Decolorized.	650	Color restored.
99	639	Decolorized.	639	Color restored.
100	*584	Decolorized.	*584	Color restored.
101	**448	Decolorized.	**448	Color restored.
102	***425	Not decolorized.	***425	
103	426	Not decolorized.	426	
104	***451	Decolorized.	***451	Color restored.
105	452	Decolorized.	452	Color restored.
106	**427	Decolorized.	**427	Color restored.
107	428	Decolorized.	428	Color restored.
108	*197	Almost decolorized.	*197	Colorless or nearly so.
109	*201	Almost decolorized.	*201	Colorless or nearly so.
110	17	Decolorized.	17	Remains colorless or nearly so.
111	18	Decolorized.	18	Remains colorless or nearly so.
112	505	Not decolorized.	505	
113	499	Not decolorized.	499	
114	***504	Not decolorized.	***504	
115	502	Not decolorized.	502	

OXIDATION WITH BROMIN.

This test is valuable for quickly testing the color solutions obtained in the fractionation. The free acid need not be removed; though, as described in detail below, minor differences exist, depending on whether the solutions are practically neutral or markedly acid. They must not be alkaline and should be free from foreign material, though dissolved amyl alcohol, etc., does not interfere. With the oil-soluble dyes, the oxidation should be made in acetic acid of from 50 to 80 per cent strength.

The chief practical use of the test is for the detection of the azo and the azin dyes, especially when in admixture with natural coloring matters. It provides the simplest means for the identification of the "first component" of the azo colors, for which, of course, well-known reduction methods may also be applied. The test is made as follows: About 5 cc of the dye solution (preferably of concentration in the neighborhood of from 0.005 to 0.01 per cent) are treated with bromin water (1 per cent) added drop by drop until a little more has been used than is required to destroy the dye. A few drops of 3 per cent hydrazin sulphate solution are then added and the mixture divided into two portions. To one is first added a few drops of alcoholic alpha-naphthol solution, then excess of sodium carbonate; to the other, sodium carbonate only. With azo compounds sodium formate may be substituted for the hydrazin salt.

The reactions obtained are referred to classes as follows:

Class A—Azo dyes.—These yield on oxidation in acid or neutral solutions a diazo compound corresponding to the "first component" of the dye.[1] The azo group remains attached to the nonhydroxylated or nonaminated residue, and it is noteworthy that with Chrysophenin (No. 329), the one azo color described in the table containing neither hydroxyl nor amino groups, the usual reaction is not obtained. With dis-azo colors of the type of cotton scarlet, $C_6H_5N_2$-$C_6H_4N_2C_{10}H_5OH(SO_3Na)_2$, the azo group between the two nonhydroxyl-containing residues is not readily attacked, so that a diazo-azo compound is formed. With dyes of class A the solution becomes colorless, pale yellow, or pale orange on addition of bromin. After adding the hydrazin sulphate the solution is colorless or pale brownish or pinkish, a tendency to show a slight coloration being more marked, the more nearly neutral the solution. Addition of sodium carbonate alone produces no marked coloration, but alpha-naphthol, followed by the carbonate, gives a pronounced color. It is advisable to add some ether to the colored mixture and shake; since if the first component of the original dye was an unsulphonated amin (indicated by "e" in the table) the new coloring matter formed will be taken up by ether from the alkaline mixture, giving usually an orange solution that on being poured off and treated with a large excess of concentrated hydrochloric acid becomes, in most cases, violet or blue. If the new dye is sulphonated (indicated by "w"), it will not be extracted by the ether from the mixture. When desired, the alpha-naphthol derivative, after separation by a suitable solvent, may be dyed on wool or silk and further identified by the ordinary spot tests with acids and alkalies. See tables for solubilities and reactions of Orange I (No. 85), Fast brown N (No. 101), benzeneazo-α-naphthol, and α-naphthaleneazo-α-naphthol (serial numbers in tables: 55, 66, 122, 123, respectively).

Other compounds, such as α-naphthylamin, readily coupling with diazo compounds, may, of course, be used instead of the α-naphthol, sodium acetate being substituted for the sodium carbonate when an amin is employed. With the simple monazo colors, the reaction seems almost quantitative. With benzidin dyes it takes place least smoothly.

Class AA—Azo dyes, reacting like the preceding class in solutions that contain a considerable amount of free hydrochloric acid (perhaps one-half normal or above).—In neutral solutions other oxidation

[1] For action of halogens on azo compounds, see M. Schmidt, J. prakt. Chem. **84** (1912), 235. Oxidation by lead peroxid, Lauth, Bul. Soc. Chim. **6** (1891) III, 94; by nitric acid, O. Schmidt, Ber. Chem. Ges. **38** (1905), 3201, 4022. See also Meldola, Proc. Chem. Soc. **10** (1894), 118, and Trans. Chem. Soc. **55** (1889), 608, and **65** (1894), 841.

reactions take place, so that a more or less strong coloration is produced on treatment with sodium carbonate without previous addition of the naphthol. Crystal Scarlet (No. 64), Bordeaux B (No. 65), and Palatine Red (No. 62) give strong blue colorations; Naphthol Black (No. 88) and Amaranth (No. 107) a less intense blue color. Azorubin (No. 103) gives a purple changing to bluish red, but not very intense. Except for the first three dyes named, the colorations are considerably less intense than the original dyes, and the reaction much less trustworthy and valuable than the smooth, almost quantitative, reaction in acid solutions. When treated with bromin in solutions containing sodium carbonate (one-fourth normal), Nos. 62, 64, and 65 are bleached, becoming intensely blue on addition of hydrazin sulphate.

Class B.—Azin derivatives,[1] *etc.*—On treatment with bromin in neutral or acid solutions, the color is readily bleached, but is restored on adding hydrazin sulphate. Sodium carbonate and alpha-naphthol plus sodium carbonate produce no change other than that shown by the original dye solution on treatment with alkali. A few dyes of Classes A and AA when oxidized in neutral solutions tend to show a rather marked coloration on adding the hydrazin sulphate. However, with the typical members of Class B, the dye may be bleached and restored a number of times by careful alternate addition of the two reagents, the bromin apparently forming a nearly colorless compound reconverted into the original dye on addition of the hydrazin sulphate.

Class C.—Colors giving precipitates at dilutions as high as 0.01 per cent.—This class includes most of the basic dyes.

Class D.—Colors showing marked changes in tint in neutral or very faintly acid solution on addition of bromin.[2]—The colorations are usually produced by a mere trace of the halogen and destroyed by excess, and the reactions are consequently not very dependable or valuable. With many of the dyes of this type containing alkylated amino groups the color change would seem to be due to elimination of alkyl radicals. In general with dyes of this group the coloring matter, while readily altered, is completely broken down by bromin only with difficulty. On addition of hydrazin sulphate no change takes place other than that due to removal of the excess of the colored halogen.[3] The coloration with alpha-naphthol and sodium carbonate is identical with that produced by sodium carbonate alone. With most of the yellow coloring matters of this group it is

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[1] Quinophthalon by treatment with bromin first forms the unstable colorless addition product containing two atoms of bromin in the molecule (Eibner and Lange, Liebig's Annalen der Chemie, **315** (1901), 315). For action on azin dyes compare Vaubel, J. prakt. Chem., **54** (1896), 289.

[2] According to Heumann, Die Anilinfarben, vol. 1, p. 41, Malachite Green solution, on oxidation with lead peroxid and acetic acid, becomes violet, and then contains the salt of diaminotriphenylcarbinol. Compare further Vaubel, J. prakt. Chem., **50** (1894), 347.

[3] Chlorin water may be used if preferred.

brownish. With most of the others it is ill-defined and is probably often produced by a small fraction of the dye that has escaped destruction by bromin. In acid solution these dyes are merely destroyed by bromin in most cases, the results being as given for E.

Class E.—Dyes in this class are similar to those in Class D, but show no color changes other than bleaching, on addition of bromin.

Class F.—Halogenated fluorescein derivatives and similar compounds.—These dyes are very resistant to bromin. The nonfluorescent iodin compounds tend to become yellower in shade and to develop a green fluorescence, probably due to partial substitution of iodin by bromin.

TABLE 4.—*The bromin test: Classification of colors according to reactions obtained.*

[Numbers denoting permitted dyes are in boldfaced type; natural colors are in italics. Dyes common in foods are starred, three stars indicating those most often found. Statements apply in general to 0.01 per cent solutions.]

No.	Coloring matter.	Class.
1	*462	D or E.
2	434	D.
3	**435**	D.
4	*436	D.
5	439	E.
6	491	D or E.
7	440	E.
8	**602	E (B).[1]
9	**108	A (w).
10	***8	A (w).
11	9	A (w).
12	**89	A (w).
13	**692**	E.
14	399	A (w).
15	***106	A (w).
16	**107**	AA or A (w).
17	**94**	A (w).
18	*398	E.
19	605	B.
20	604	B.
21	188	AA (w).
22	**14	A (e).
23	21	A (e).
24	318	A.[1]
25	20	A (e).
26	93	A or AA (w).
27	***480	D.
28	*53	A (e).
29	*55	A (e).
30	105	A (w).
31	**4**	E.
32	****706*	E.

No.	Coloring matter.	Class.
33	**56**	A (e).
34	*62	AA (e).
35	**64	AA (e).
36	*65	AA (e).
37	**103	A or AA (w).
38	139	A or AA (w).
39	164	A (w).
40	**667	B.
41	*169	A (w).
42	163	A (w).
43	170	A (w).
44	84	A (w).
45	146	A (e).
46	287	A.[1]
47	78	A.[2]
48	****710*	E.
49	*546	B.[1]
50	1	E.
51	507	D.
52	328	A (w).
53	606	B.
54	154	A (e).
55	**85**	A (w).
56	**13	A (e).
57	***86	A (w).
58	97	A (w).
59	54	A (e).
60	329	E.
61	139	A (w).
62	157	A (e).
63	*95	A (w).
64	88	A (w).

No.	Coloring matter.	Class.
65	*92	A (w).
66	101	A or AA (w).
67	102	A (w).
68	483	E.
69	*510	(3)
70	26	A (e).
71	220	A.[1]
72	269	A.[1]
73	512	E.
74	515	E.
75	516	E.
76	**517**	E.
77	518	E.
78	520	E.
79	521	E.
80	*523	E.
81	2	E.
82	*3	E.
83	6	E.
84	*534*	B.
85	****707*	E.
86	*10	A (e).[4]

No.	Coloring matter.	Class.
87	*468	E.
88	464	E.
89	438	D.
90	**433	D.
91	442	E.
92	476	E.
93	240	A.[5]
94	277	A.
95	562	B.
96	658	E.
97	496	D or C.
98	650	E or C.
99	639	E or D.
100	*584	B or C.
101	**448	E or D.
102	***425	E or C.
103	426	E or C.
104	***451	E or C.
105	452	E or C.
106	**427	D or C.
107	428	D or C.
108	*197	A or C.
109	*201	A or C.
110	17	A or C (e).
111	18	A or C (e).
112	505	D or C.
113	499	D or C.
114	***504	D or C.
115	502	D or C.
(4)		

[1] Imperfectly.
[2] Some alcohol should be added before the alpha-naphthol.
[3] Gives eosin.
[4] Of the oil-soluble dyes given in the other tables all belong to type A except Quinophthalon, which in 60 per cent acetic acid shows reaction indicated under B.
[5] Very imperfectly.

REACTIONS WITH NITROUS ACID.

By treatment with nitrous acid in dilute solution most of the common coal-tar dyes used in food coloring are not readily affected. A considerable number, however, show marked changes, because of diazotization of free amino groups, of formation of nitroso compounds, or of direct oxidation.

Where diazo compounds are formed, they may be further coupled by the usual method of adding the mixture to an alkaline solution of one of the naphthols, or of a naphthol sulphonic acid. B. C. Hesse has pointed out that the two acid yellows (No. 8 and No. 9) can be distinguished by the use of alpha-naphthol—No. 9 giving in alkaline solution a red compound; No. 8 one which is intensely blue.

In the test described below the mixture is treated first with nitrous acid, then with hydrazin sulphate. The hydrazin sulphate serves to destroy the excess of nitrous acid, so that the naphthol solution (or an amin if preferred) may be added directly, and the coupling then brought about by addition of alkali. The new dye formed may also be separated readily, if desired, by acidifying and shaking out with a suitable solvent. In the case of only one dye in the table, Safranin (No. 584), does the diazo compound appear to be reduced or changed by addition of hydrazin sulphate.

The nitroso compounds formed from Nos. 95 and 88, are decomposed by the hydrazin salt, the original color of the acid solution being restored.

The test is carried out as follows: The solution of the color at ordinary temperature is made slightly acid by the addition of two or three drops of concentrated hydrochloric acid and one or two drops of 7 per cent sodium nitrite solution are added. With blue or green dyes, where oxidation changes may take place, the mixture may be allowed to stand a few minutes at this stage; but with other colors about 1 cc, or an excess, of 3 per cent hydrazin sulphate solution is added at once. The mixture is allowed to stand one-half or one minute to permit complete destruction of the excess of nitrous acid; then it is divided and a few drops of alpha-naphthol solution are added to one portion. Both portions are then made strongly alkaline with sodium carbonate, the one not containing alpha-naphthol serving as a check to show if any coupling has taken place.

TABLE 5.—*Behavior of colors when treated with sodium nitrite.*

[° Indicates that no color changes take place other than those produced by the acid or alkali.]

462.—With sodium nitrite, blue; then colorless; after making alkaline in the presence of alpha-naphthol, orange.

434°, 435°, 436°.—Attacked very slowly by nitrous acid.

439.—Becomes yellow with sodium nitrite.

491.—Becomes violet with sodium nitrite (rather slowly).

440°, 602°, 108°.

8.—With sodium nitrite, much paler; after adding alpha-naphthol and *excess* of sodium carbonate, intensely blue.

9.—With sodium nitrite, much paler; after adding alpha-naphthol and *excess* of sodium carbonate, red.

89.—Red solution becomes yellow with sodium nitrite; on addition of hydrazin sulphate, red again.

692.—With sodium nitrite, slowly oxidized to the yellow isatin derivative.

399°, 106°, 107°, 94°.

398.—With sodium nitrite, brown.

605°, 604°, 188°, 14°.

21.—With sodium nitrite, slightly darker; with alpha-naphthol and sodium carbonate, dull greenish black.

318.—With sodium nitrite, paler and redder.

20°, 93° (480°.—Slowly attacked by nitrous acid); 53°, 55°, 105°, 4°, 706°, 56°, 62°, 64°, 65°, 103°, 139°, 164°, 667°, 169°, 163°, 170°.

84.—With sodium nitrite, redder.

146°, 287°, 78°, 710°, 546°, 1°.

507.—With sodium nitrite, bluer.

328°, 606°, 154°.

85.—With sodium nitrite, paler.

86°, 54°, 13°, 97°, 329°, 139°, 157°.

95.—Crimson solution becomes yellow with sodium nitrite; on addition of hydrazin sulphate, red again.

88.—Crimson solution becomes yellow with sodium nitrite; on addition of hydrazin sulphate, red again.

92°.

101.—Paler with sodium nitrite.

102°, 483°, 510°, 26°.

220, 229.—Slightly paler with sodium nitrite.

512°, 515°, 516°, 517°, 518°, 520°, 521°, 523°, 2°, 3°, 6°, 534°, 707°, 10°, 468°, 464°, 438°, 433°, 442°, 476°, 240°, 277° (562°, scarcely attacked; in 50 per cent acetic acid, behaves with nitrous acid as with bromin in the bromin test); 658°, 496°, 650°, 639°.

584.—With sodium nitrite, blue; rather rapidly becomes red again on addition of hydrazin sulphate.

448.—Wine-red on diazotization, addition of hydrazin sulphate, alpha-naphthol and sodium carbonate; with sodium nitrite in acetic acid solution, first blue, then colorless.

425°, 426°, 451°, 452°.

427.—Reddish with sodium nitrite.

197°, 201°.

17.—With sodium nitrite, paler; after addition of sodium carbonate, naphthol, etc., somewhat redder.

18.—With sodium nitrite, paler; after addition of sodium carbonate, naphthol, etc., somewhat redder.

505°, 499°, 504°, 502°.—May appear bluer when the alcoholic alpha-naphthol solution is added.

16°.—Slowly destroyed by nitrous acid.

7.—Paler with sodium nitrite; after addition of other reagents, red.

Aminoazotoluene.—As stated above for 7.

Benzeneazo-β-naphthylamin, Ortho-tolueneazo-β-naphthylamin.—These compounds are almost insoluble in aqueous liquids. As ortho-aminoazo derivatives, they are not readily diazotized or coupled.

REACTIONS WITH POTASSIUM CYANID.

With the common monazo dyes, the bromin oxidation will provide for an identification of the "first component" of the color, i. e., the radical not containing the hydroxyl or amino groups. The other radical, usually containing hydroxyl or amino groups ortho to the azo junction, is identified with much more difficulty in most cases. Since the two ortho-azo dyes permitted in foods are both derived from 2-naphthol-3-6-disulphonic acid as second component, the reaction discovered by Lange[1] that derivatives of this acid are attacked on boiling with potassium cyanid and the 3-sulphonic acid group replaced by cyanogen, is useful for distinguishing and separating isomeric dyes.

The test may be made as follows: About 10 cc of the neutral color solution is treated with 1 cc of 20 per cent potassium cyanid solution

[1] Deutsches Reichs Patent No. 189,035.

and 1 cc of 20 per cent ammonium chlorid solution, and is heated in a test tube in a boiling water bath for from five to eight minutes. It is then quickly cooled. The reactions obtained with certain dyes are shown in the table. The test requires some care, and blanks with known dyes should be carried through at the same time in all cases.

The results with a number of common azo dyes are shown in Table 6, the derivatives of 2-naphthol-3-6-disulphonic acid forming new dyes of markedly different solubilities, corresponding to the fact that they contain one less sulphonic acid group. By warming with the cyanid solution for a considerable period of time further reactions easily take place, derivatives of 2-naphthol-3-6-disulphonic acid and 2-naphthol-6-8-disulphonic acid being especially unstable.

The common nitro dyes are changed by warming with cyanid solution, becoming brownish or reddish (compare formation of isopurpuric acid from trinitrophenol).

TABLE 6.—*Behavior of colors with cyanid solution.*

Dye.	"Second component" of dye.	Behavior with cyanid solution.
108	Naphthol trisulphonic acid (2-3-6-8).	Warmed 8 minutes, dye almost completely destroyed with production of orange and yellow substances. Warmed until dark red (1-2 minutes), strongly acidified, and washed with 2 N HCl, practically no color is removed (3-4 washings); then washed with N/4 HCl, a bluish red dye is readily removed.
Azorubin S. G.		Apparently unchanged by cyanid.
106	Naphthol disulphonic acid (2-6-8).	Dye is not changed in solubility, although on long warming much color is destroyed. The cyanid mixture may be acidified with 5 cc concentrated hydrochloric acid, and shaken out with 10 cc of amyl alcohol. On separating the alcohol, and washing 4 or 5 times with fourth-normal hydrochloric acid, nearly all of the dye will be taken out by the dilute acid.
107	Naphthol disulphonic acid (2-3-6).	Dye is changed into a cyan-derivative similar in solubility to other disulphonated monazo dyes. The cyanid mixture is pale brown and when treated as stated under New Coccin (106), almost all coloring matter remains in the amyl alcohol. On long heating of the cyanid mixture the cyan-derivative may be completely destroyed, further reactions taking place.
14	Naphthol disulphonic acid (2-6-8).	Dye unchanged. Cyanid mixture, when acidified with 1 cc glacial acetic acid and shaken with 5 to 10 cc amyl alcohol, gives up little coloring matter to the latter.
15	Naphthol disulphonic acid (2-3-6).	Dye changed into a cyan-derivative similar in solubility to the other monosulphonated monazo dyes. The cyanid mixture is pale brownish, and when treated as described under Orange G (14) gives up most of its coloring matter to the alcohol.
20	Dioxynaphthalene disulphonic acid (1-8-3-6).	As stated for 14.
21	Aminonaphthol disulphonic acid (1-8-3-6).	As stated for 14.
52	Naphthol disulphonic acid (1-4-8).	As stated for 14.
53	Naphthol disulphonic acid (1-3-6).	As stated for 14.
55	Naphthol disulphonic acid (2-3-6).	As stated for 15.
56	Naphthol disulphonic acid (2-3-6).	As stated for 15.
62	Naphthol disulphonic acid (1-3-6).	As stated for 14.
64	Naphthol disulphonic acid (2-6-8).	As stated for 14.
65	Naphthol disulphonic acid (2-3-6).	As stated for 15.

NATURAL COLORING SUBSTANCES.

Relatively few good tests are known for the common natural colors. For properties useful in analysis, see especially the tables given in United States Department of Agriculture, Bureau of Chemistry Circular No. 63. Some of the common properties considered most useful for the characterization of different colors are summarized below.

By addition of concentrated hydrochloric acid, the yellow ether or alcohol solutions of carotin and xanthophyll show little change, becoming perhaps slightly paler; green chlorophyll solutions become yellower or browner; annatto in ether or alcohol solution remains orange, not changing perceptibly with acid. Turmeric solutions in ether or alcohol show a pure yellow color with more or less green fluorescence, and on addition of several volumes of concentrated hydrochloric acid the color passes to orange red or carmine red. The orange or orange yellow solutions of logwood, also of the redwoods, barwood, sandalwood, camwood, and brazilwood, become deep red with excess of hydrochloric acid. The slightly colored neutral or faintly acid aqueous solutions of the flavone colors of fustic, Persian berries, quercitron, etc., become intensely yellow with from 2 to 4 volumes of concentrated acid. Neutral or slightly acid solutions of cochineal, archil, saffron, and caramel show little change.

The slightly acid solutions of the various coloring matters show the behavior described below, when treated with a little sodium hydrooxid solution: Carotin and xanthophyll, little change; chlorophyll, "brown phase" reaction; alkanet, deep blue; turmeric, orange brown; the redwoods, violet red; logwood, violet to violet blue. The flavone colors become bright yellow; saffron remains yellow, showing little change. The red solutions of archil and the orange of cochineal become blue and violet, respectively. Caramel shows little change, becoming slightly deeper brown. The red fruit colors (in presence of air) become dull blue, green, or brown.

By sodium hydrosulphite in acid solution, the yellow coloring matters are little affected. Logwood is almost decolorized, the color returning imperfectly. Archil is decolorized, the color returning when shaken with air. The reaction is more easily seen in alkaline solution. Cochineal shows no marked change. The anthocyanidins derived by hydrolysis from the red fruit colors are almost decolorized by hydrosulphite. Caramel is rendered slightly paler.

In the bromin test all coloring matters, except alkanet, are merely destroyed more or less completely by the halogen, hence they belong in general to Class E. The flavone colors tend to become darker with the first addition of bromin. Alkanet (best in alcoholic solution) corresponds to Class B.

Ferric chlorid gives no marked change with annatto, turmeric, or saffron, these perhaps, appearing somewhat browner. With the flavone colors, colorations varying from dark olive green to black are produced. With the redwoods and logwood, very dark shades of violet, brown, or black are obtained. Cochineal becomes somewhat darker. Caramel is not affected. The solutions must be practically neutral.

By addition of alum solution the yellow color of logwood is changed to rose red (rather slowly). The redwoods are affected similarly. The pale yellow solutions of the flavones become more strongly yellow, that of fustic developing a green fluorescence. Saffron and turmeric show little change.

Uranium acetate in neutral or nearly neutral solutions gives orange colorations with the flavones. Turmeric becomes somewhat browner; saffron is not affected; cochineal becomes green; alkanet, yellowish green to bluish green; logwood, violet, quickly fading.

The coloration with concentrated sulphuric acid dropped on the dry coloring matter is for carotin and xanthophyll, blue, usually obtained with difficulty. Annatto and saffron also give blue colors; turmeric, a red; the flavone colors, yellow or orange colorations; alkanet and archil give violet blue; logwood, red, changing to yellow.

The "brown phase" reaction[1] may be useful for the characterization of chlorophyll, when this has not been previously treated with alkalies. The green ether or petroleum ether solution of the coloring matter, when treated with a little methyl alcohol solution of potassium hydroxid, becomes brown, returning to green in a few moments.

The characteristic reaction of curcumin (turmeric) with boric acid may be conveniently carried out as follows: The aqueous or dilute alcoholic solution of the color is treated with hydrochloric acid until the shade just begins to appear slightly orange. The mixture is then divided into two parts and some boric acid powder or crystals added to one part. A marked reddening quickly will be apparent, best seen by comparison with the portion to which the boric acid has not been added.[2]

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[1] Molisch, Ber. bot. Ges. **14** (1896), 16. Willstaetter and Stoll, Untersuchungen ueber Chlorophyll. Berlin, 1913, p. 144.

[2] The properties of pure preparations of the various natural coloring matters, as described by the numerous investigators who have isolated and studied them, are described for the most part in H. Rupe's *Chemie der Natürlichen Farbstoffe*, Braunschweig, 1900 and 1909. Properties of the chlorophylls and cartinoids are given by Willstaetter and Stoll, *Untersuchungen ueber Chlorophyll*, Berlin, 1913; those of the coloring matters of the cornflower, rose, pelargona flower, larkspur, cranberry, whortleberry, and purple grape, are described by Willstaetter and coworkers. Sitzb. kgl. Pruess. Akad. 12 (1914), 402, Liebigs Ann. d. Chem. 408 (1915) 1.

TABLE 7.—*Numbers by which dyes are designated in different published tables.*

[Under "G." numbers refer to *A Systematic Survey of the Organic Coloring Matters*, by A. G. Green, founded on the German of Drs. G. Schultz and P. Julius, London and New York, 1904; under "S." to *Farbstofftabellen*, by Dr. Gustav Schultz, Berlin, 1911–1914, under "M." to Mulliken's *A Method for the Identification of Pure Organic Compounds*, vol. 3, New York, 1910. One of the common names is also given.]

No.	Color.	G.	S.	M.
1	Acid Magenta.	462	524	245
2	Light Green S F Bluish.	434	504	
3	Light Green S F Yellowish.	435	505	257
4	Erioglaucin A.	436	506	287
5	Cyanol Extra.	439	546	285
6	Wool Green S.	491	566	279
7	Patent Blue.	440	543	277
8	Nigrosin Soluble.	602	700	122
9	Ponceau 6 R.	108	170	846
10	Acid Yellow G.	8	137	918
11	Fast Yellow R.	9	149	
12	Brilliant Yellow S.	89	142	
13	Indigo Carmine.	692	877	94
14	Sun Yellow.	399	9	166
15	New Coccin.	106	169	826
16	Amaranth.	107	168	811
17	Tartrazin.	94	23	948
18	Naphthol Green B.	398	4	951
19	Azocarmine B.	605	673	75
20	Azocarmine G.	604	672	71
21	Naphthol Black B.	188	272	984
22	Orange G.	14	38	
23	Fast Acid Fuchsin B.	21	41	
24	Chicago Blue 6 B.	318	424	575
25	Chromotrope 2 R.	20	40	
26	Azofuchsin G.	93	146	757
27	Soluble Blue.	480	539	212
28	Palatine Scarlet.	53	81	
29	Ponceau 2 R.	55	82	834
30	Fast Red E.	105	166	
31	Naphthol Yellow S.	4	7	946
32	Cochineal.	706	932	774
33	Ponceau 3 R.	56	83	833
34	Palatine Red.	62	109	
35	Crystal Ponceau.	64	113	843
36	Bordeaux B.	65	112	778
37	Azorubin.	103	163	783
38	Fast Brown.	139	213	
39	Crocein Scarlet O extra.	164	251	
40	Quinolin Yellow water-soluble.	667	613	
41	Crocein Scarlet 8 B.	169	255	802
42	Biebrich Scarlet.	163	247	800
43	Bordeaux G.	170	254	1,133
44	Resorcin Yellow.	84	143	830
45	Brilliant Crocein M.	146	227	
46	Azo Blue.	287	377	689
47	Erika B.	78	121	
48	Azolitmin.	710	934	
49	Alizarin Red S.	546	780	1,111
50	Picric Acid.	1	5	947
51	Violamin R.	507	582	1,101
52	Brilliant Yellow.	328	303	
53	Rosindulin 2 G.	606	674	78
54	Cloth Red B.	154	236	371
55	Orange I.	85	144	871
56	Crocein Orange.	13	37	877
57	Orange 2.	86	145	872
58	Orange R.	97	151	
59	Scarlet G R.	54		
60	Chrysophenin.	329	304	524
61	Resorcin Brown.	137	211	451
62	Bordeaux B X	157	237	1,132
63	Metanil Yellow.	95	134	901
64	Orange IV.	88	139	900
65	Azoflavin.	92	140	910
66	Fast Brown N.	101	160	849
67	Fast Red A.	102	161	777
68	Rosolic Acid.	483	555	249
69	Uranin.	510	585	1,141
70	Metachrome Orange R.	26	58	893
71	Chrysamin G.	220	342	1,061
72	Chrysamin R.	269	394	1,060
73	Eosin.	512	587	1,129
74	Saffrosin.	515	590	1,114
75	Erythrosin G.	516	591	
76	Erythrosin B.	517	592	1,113
77	Phloxin.	518	593	1,107
78	Rose Bengale.	520	595	1,109
79	Eosin 10 B.	521	596	1,112
80	Rose Bengale 3 B.	523	597	1,103
81	Victoria Yellow.	2		
82	Martius Yellow.	3	6	945
83	Aurantia.	6		897
84	Alizarin.	534	778	905
85	Curcumin.	707	927	535
86	Sudan G.	10	35	536
87	Formyl Violet S 4 B.	468	530	307
88	Acid Violet N.	464	527	309
89	Night Green 2 B.	438	503	265
90	Guinea Green B.	433	502	259
91	Patent Blue A.	442	545	278
92	Methyl Alkali Blue.	476	535	196
93	Congo Red.	240	307	412
94	Benzopurpurin 4 B.	277	363	1,020
95	Alizarin Blue.	562	803	1,168
96	Thioflavin T.	658	618	1,084
97	Rhodamin S.	496	570	143
98	Methylene Blue.	650	659	23
99	New Blue.	639	649	34
100	Safranin.	584	679	8
101	Fuchsin.	448	512	139
102	Auramin O.	425	493	1,085
103	Auramin G.	426	494	
104	Methyl Violet.	451	515	232
105	Crystal Violet.	452	516	229
106	Malachite Green.	427	495	177
107	Malachite Green G.	428	499	170
108	Bismarck Brown.	197	283	454
109	Bismarck Brown R.	201	284	1,030
110	Chrysoidin.	17	33	509
111	Chrysoidin R.	18	34	
112	Rhodamin 3 B.	505	574	1,002
113	Irisamin G.	499	576	1,012
114	Rhodamin B.	504	573	1,001
115	Rhodamin G.	502	572	1,101
116	Butter Yellow.	16	32	
117	Anilin Yellow.	7	31	932
118	Yellow Fat Color.		68	
121	Quinolin Yellow spirit soluble.	666	612	
123	Sudan Brown.	59	105	
125	Sudan I.	11	36	887
126	Sudan II.	49	76	1,026
127	Carminaph Garnet.	60	106	
128	Sudan III.	143	223	
129	Sudan IV.		232	839
130	Para Red.	31	56	

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 449

Contribution from the States Relations Service
A. C. TRUE, Director

Washington, D. C. PROFESSIONAL PAPER October 31, 1916

A STUDY OF THE ELECTROLYTIC METHOD OF SILVER CLEANING.[1]

By H. L. LANG and C. F. WALTON, Jr., *Scientific Assistants, Office of Home Economics.*

CONTENTS.

	Page.
Introduction	1
Preliminary tests	3
Principle of the electrolytic method	4
Experimental study of the method	5
A household method	11
Summary	11

INTRODUCTION.

An understanding of the factors which influence the tarnishing of metals and a knowledge of efficient methods for removing tarnish are necessary for the proper care of household equipment. An extended study of these problems, therefore, is being made by the Office of Home Economics, and the work reported in this paper is a part of this investigation.

The tarnishing of metals in general is due to the formation of oxids or basic oxids of the metals by the chemical action of the oxygen and water vapor of the air to which they are exposed. In the light of recent investigations a distinction is made between rusting, or oxidation, and the corrosion of metals. Thus, the rusting of iron may be regarded as taking place in two steps: The displacement of the hydrogen ions of water with the formation of a small amount of soluble iron salts in the lower state of oxidation is technically termed corrosion, while true rusting is the oxidation

[1] Prepared under the direction of C. F. Langworthy, Chief, Office of Home Economics.

NOTE.—This bulletin contains information regarding the advantages and limitations of the electrolytic method of cleaning silver and the conditions under which it is most efficient, which it is believed will prove useful to teachers and housekeepers generally.

of these salts. Iron rust, then, consists principally of ferric oxid in admixture with varying amounts of basic ferric oxid. In the case of metals like copper and zinc, and alloys like brass and bronze, basic salts are also formed. For example, copper reacts with water vapor and carbon dioxid in the air to form a basic carbonate, while in the presence of weak organic acids it forms salts like basic copper acetate (verdigris).

Unlike most other metals, silver and gold are not tarnished by the oxygen, water vapor, or carbon dioxid present in the air, or by the action of weak organic acids. Silver, however, readily forms black silver sulphid on coming in contact with sulphur compounds, small quantities of which are found in the air as the result of burning coal and illuminating gas, while larger amounts occur in vulcanized rubber, wool, and foods like eggs. The problem of cleaning silver involves the removal of the tarnish of silver sulphid by some method which will also restore the polish to the surface of the metal.

The two general methods for cleaning silver are polishing with a finely divided abrasive material to cut away the tarnish mechanically and the use of suitable chemical compounds to dissolve the coating of silver sulphid. The first method is the more common one, and commercial silver polishes usually contain a suitable abrasive, such as tripoli, rouge, double-floated silica, kieselguhr, whiting, or pumice, which are prepared in the form of a powder, a cake, or a suspension in some liquid. As silver is a comparatively soft metal, and since the process of cleaning depends essentially on the cutting away of the tarnish by the sharp particles of the polishing powder, care must be taken to choose an abrasive so finely powdered that it will not scratch the silver. Solvent polishes are often used by jewelers and in hotels and restaurants where large quantities of silver must be cleaned. As a rule these consist principally of potassium cyanid and sometimes contain ammonia, both of which dissolve the sulphid coating and give the silver a beautiful satin finish. As cyanids are extremely poisonous and very dangerous when carelessly handled, they should not be commonly used for cleaning purposes.

A few years ago the so-called electrolytic method for cleaning silver was introduced to the public and several forms of cleaners, based on the electrolytic principle, are now to be found on the market. In this method the silver is cleaned by bringing it into actual contact with aluminum in a solution of an electrolyte. As this form of cleaning is becoming quite extensively used and questions are frequently asked about its efficiency and its effect on the silver, information is desirable regarding the principle and details of the process. The main object of this investigation, therefore, was to determine the value of the method and the factors necessary for its efficient operation under household conditions. Preliminary tests were made to determine the efficiency of some representative commercial cleaners of this type and to study the nature of the metals and electrolytes commonly used.

PRELIMINARY TESTS.

The first type of electrolytic cleaner to be tested consisted of a zinc pan, on the bottom of which was fastened an aluminum grating. The directions furnished by the manufacturers for the use of this device were followed. The tarnished silver was placed on the grating and the pan filled with a dilute solution of ordinary washing soda and salt (1 teaspoonful of each to 1 quart of water) to such a height that the silver was completely covered. The liquid was kept at the boiling point until the tarnish disappeared from the silver, which was then rinsed with hot water and wiped dry. From the results of laboratory tests, in which a number of pieces of tarnished silver were cleaned by this method, it was concluded that the apparatus, although efficient, possessed no particular advantages over other less expensive methods. If a large quantity of silver is to be cleaned, however, the comparatively large capacity of the zinc pan makes the apparatus convenient. A less expensive form of this cleaner consists only of a zinc disk to the top of which are welded some aluminum wire grids. This may be used in any kettle, or in a wash boiler if large pieces of silver are to be cleaned. The silver must be placed in direct contact with the wire grids.

Still other cleaners are on the market which make use of pieces of sheet metal of various shapes. In some cases the metal alone is sold as the essential part of the "magical" method, and the instructions given with it state that the silver should be placed in contact with the metal in boiling water containing a small amount of either washing or baking soda or a mixture of one of these with common salt.

Other electrolytic cleaners consist of packages which contain a strip of metal and a powder to be dissolved in water to form the cleaning solution. Two of these were analyzed in the laboratory. The metal proved to be very pure aluminum of the spun variety, and the powder was found to consist essentially of a mixture of soda and salt.

The cleaning tests conducted in the laboratory indicated that in general tarnished silver could be cleaned equally well by all of these commercial devices. The advantages of size and convenience possessed by some seemed to correspond in every case to an increased market price, although the wide range in price makes possible the selection of a cleaner to suit a variety of conditions. These preliminary experiments were of value in supplying information as to the general nature of the factors involved in the electrolytic method.

PRINCIPLE OF THE ELECTROLYTIC METHOD.

Success in using the electrolytic silver cleaners depends upon bringing the tarnished silver into actual contact with a more active metal when both are immersed in a solution of some suitable electrolyte. When so immersed aluminum and zinc are electrolytically more active than silver, or, chemically speaking, they are said to be electropositive referred to silver. In the presence of either sodium carbonate or sodium chlorid, or a mixture of both, aluminum forms aluminum ions in the solution and itself becomes negatively charged. The silver accordingly becomes positively charged as the current flows from the aluminum to the silver through the solution. In other words, such an arrangement of metals in an electrolyte may be considered to be an electrolytic cell.

Since silver sulphid is slightly soluble, a small number of silver and sulphid ions are always present in the solution, and the silver ions will give up their positive charges of electricity and plate out on the silver or negative pole as silver atoms. Any agency making the silver sulphid more soluble will increase the number of silver and sulphid ions and, provided the silver ions are plated out as rapidly as they are formed, this will increase the rate of the reaction. Moreover, in accordance with the law of mass action, the greater the number of aluminum ions formed in the solution, the greater will be the tendency for silver sulphid to be reduced to metallic silver. The conditions are apparently most favorable to the completion of the reaction when a dilute solution of sodium carbonate is used as the electrolyte. The hydrolysis of this salt furnishes a fairly strong alkaline solution.

(1) $$Na_2CO_3+2H_2O \rightarrow H_2O+CO_2+2NaOH.$$

Aluminum then displaces hydrogen from a boiling solution of the alkali.

(2) $$Al+3NaOH \rightarrow Na_3AlO_3+3H.$$

The atomic hydrogen supplied by this reaction reduces the silver sulphid.

(3) $$Ag_2S+2H \rightarrow H_2S+2Ag.$$

When an excess of hydrogen ions is continually being formed, the sulphid ions are gradually removed to form molecules of H_2S. In this way the equilibrium between Ag_2S (undissociated) and its ions is disturbed, and accordingly more Ag_2S dissolves. The reaction finally is completed and, since the excess of aluminum ions plates out the silver on the silver pole, practically no silver is lost.

EXPERIMENTAL STUDY OF THE METHOD.

It was the chief purpose of these experiments to obtain information as to the best metal and electrolyte to use, the most economical concentration of the solution, and the most satisfactory temperature for cleaning silver as it would ordinarily be accomplished in the home, and to study the relative efficiency of the electrolytic and other methods.

Throughout the investigation the methods and apparatus were simple and in most cases applicable to household use, more accurate procedure being deemed impracticable. In some cases silver which had been naturally tarnished by use was cleaned satisfactorily by this method, but in order to secure uniform conditions the silver used in most tests was tarnished by immersing it in a strong potassium-sulphid solution, and in order that the tarnish should be uniform for a comparative series of tests, all of the spoons to be used in each series were placed in the sulphid solution for the same length of time. Porcelain or agate ware dishes were used for holding the solution of electrolyte, which was made up by adding different amounts of soda and salt, etc., to one or two quarts of water. The active metal used, aluminum, or zinc, or an alloy of both, and the tarnished silver were then placed in direct contact in the solution which had previously been heated to the desired temperature, and the time necessary for cleaning was noted by a stop watch.

Since the preliminary tests indicated that either washing or baking soda may be used as the electrolyte of the cleaning solution, it seemed desirable to ascertain first of all whether either of these salts was the more efficient and economical for ordinary household use. Experiments were accordingly made to determine the relative efficiency of solutions of washing soda and baking soda without the addition of sodium chlorid. The concentration of the solutions was 1 teaspoonful of the commercial soda to 1 quart of water. The temperature at which the cleaning was done was approximately 100° C. in each case. In each series six spoons were used which had been tarnished as described above. The following procedure was adopted: The first spoon was cleaned in the washing-soda solution. The active metal was then rinsed in clean water, transferred to the baking-soda solution, and another spoon cleaned. By alternating from one solution to the other in this way, any error in the time of cleaning, resulting from the metal becoming corroded, was distributed equally between the two solutions. After removal from the cleaning solution the spoons were rinsed in cold water and wiped thoroughly dry with a soft cloth, rubbing very slightly.

Table I shows the results of the tests:

TABLE I.—*Comparative efficiency of solutions of washing and baking soda at the boiling temperature.*

Solution.	Time required for cleaning. Observed.	Time required for cleaning. Average.	Remarks.
Series 1.	*Seconds.*	*Seconds.*	
Washing soda	30	16	Zinc was the active metal used in series 1, 2, and 3.
Do	10		
Do	7		
Baking soda	10	10	
Do	10		
Do	11		
Series 2.			
Washing soda	240	....	The exceptionally long time required in the first test of series 2 and 3 was due to the zinc becoming corroded; it was necessary to substitute a strip of clean zinc before the tarnish was removed. In such cases the time has been disregarded in computing the average.
Do	20	18	
Do	15		
Baking soda	17	12	
Do	10		
Do	9		
Series 3.			
Washing soda	150	....	
Do	10	8	
Do	5		
Baking soda	27	13	
Do	4		
Do	8		
Series 4.			
Washing soda	5	10	Aluminum was the active metal used in series 4 to 9, inclusive.
Do	7		
Do	18		
Baking soda	6	15	
Do	10		
Do	28		
Series 5.			
Washing soda	10	11	
Do	12		
Do	10		
Baking soda	13.5	11	
Do	9		
Do	11		
Series 6.			
Washing soda	20	20	
Baking soda	30	30	
Series 7.			
Washing soda	5	4	In series 7 and 8 a small sheet of very pure aluminum of the spun variety was used.
Do	4.5		
Do	2		
Baking soda	7	6	
Do	7.5		
Do	4.5		
Series 8.			
Washing soda	8	10	
Do	12		
Do	10		
Baking soda	7.5	7	
Do	7		
Do	7		

TABLE I.—*Comparative efficiency of solutions of washing and baking soda at the boiling temperature*—Continued.

Solution.	Time required for cleaning.		Remarks.
	Observed.	Average.	
Series 9.	*Seconds.*	*Seconds.*	
Washing soda	5	4	The aluminum used in series 9 had been cleaned by polishing with emery cloth.
Do	4		
Do	2.5		
Baking soda	4	4	
Do	4		
Do	5.5		
Series 10.			
Washing soda	4	3	In series 10, 11, and 12 the active metal used was zinc. In series 10 it was cleaned after each test in dilute HCl and rinsed in water.
Do	3		
Do	2		
Baking soda	2	3	
Do	3		
Do	3		
Series 11.			
Washing soda	5	5	The zinc was not cleaned with acid in series 11.
Do	4		
Do	5		
Baking soda	3	4	
Do	3.5		
Do	4.5		
Series 12.			
Washing soda	3	5	The zinc had been standing in the hot cleaning solution for 10 minutes before use in series 12 and was not cleaned with acid.
Do	5		
Do	6		
Baking soda	5	8	
Do	7		
Do	11		

From the results of these experiments it is evident that washing soda is slightly more efficient than baking soda, the average time required, considering all of the tests, being $9\frac{1}{2}$ seconds for the washing-soda solution and $10\frac{1}{2}$ seconds for the baking-soda solution. For all practical purposes, since the difference between the efficiency of washing soda and that of baking soda is so small as to be within the limits of experimental error, it may be considered feasible to use them interchangeably. As far as the appearance of the cleaned spoons was concerned, no difference was noted in the two solutions; all the spoons that were cleaned showed a bright satin finish after each cleaning and were practically as bright at the end of each experiment as at the start. Washing soda is somewhat more economical, since it is more efficient and cheaper as well.

The next factor to be considered was the effect of increasing the conductivity of the cleaning solution, and common salt was used for this purpose. In the following experiments the silver to be cleaned was uniformly tarnished by immersing the spoons in the same tarnishing solution for the same length of time. In some of the tests aluminum was the active metal, in others zinc was used, and in a few cases an alloy, which was prepared in the laboratory by melting together zinc and aluminum. Two cleaning solutions were used: One contained 1 teaspoonful of washing soda per quart of water, and the other was made up of 1 teaspoonful each of washing soda and salt to every quart of water. The results obtained are given in Table II.

TABLE II.—*The effect of varying the concentration of the electrolyte by the addition of sodium chlorid.*

Solution.	Time required for cleaning.		Remarks.
	Observed.	Average.	
Series 13.	*Seconds.*	*Seconds.*	
Washing soda	3		
Do	5	4	Aluminium was the active metal used in series 13.
Do	3		
Washing soda+salt	2		
Do	1	1	
Do	1		
Series 14.			
Washing soda	10		
Do	4	7	In series 14, 15, and 16 zinc was the active metal, which was cleaned frequently with dilute HCl.
Do	6		
Washing soda+salt	3		
Do	3	3	
Do	3		
Series 15.			
Washing soda	3		
Do	2.5	3	
Do	2.5		
Washing soda+salt	1.5		
Do	1	1	
Do	1		
Series 16.			
Washing soda	3		
Do	2.5	3	
Do	3		
Washing soda+salt	2.5		
Do	1	2	
Do	2		
Series 17.			
Washing soda	160		
Do	15	15	The alloy of zinc and aluminum was used in series 17. The exceptionally long time observed in two instances was necessary to clean two parts of the same silver buckle, badly tarnished by use.
Do	15		
Washing soda+salt	140		
Do	12	11	
Do	10		

The data recorded in Table II indicate that the average time required for cleaning the silver was less when sodium chlorid was added to the solution. For all practical purposes, however, the difference is so slight as to be of little or no consequence. It is reasonable to assume that by increasing the concentration of the electrolyte, as is the case when sodium chlorid is added, the cleaning reaction will take place somewhat more rapidly. This conclusion is strengthened by further experiments carried out to study the effect of the concentration of the solution on the rate of cleaning. It was found, for example, that with a solution of one-tenth teaspoonful of washing soda to 1 quart of water the time of cleaning was approximately six times as long as when 1 teaspoonful was used. Conversely, the increase in the rate of the reaction when concentrations of the electrolyte as high as 1 tablespoonful to 1 quart of water were used was not sufficient to warrant the use in practice of larger amounts than 1 teaspoonful.

As a result of these tests it is believed that a teaspoonful of sodium carbonate to 1 quart of water, with or without the addition of about 1 teaspoonful of sodium chlorid, is the most satisfactory concentration of the cleaning solution for general use.

RELATIVE EFFICIENCY OF ZINC AND ALUMINUM.

A study of the tables with reference to the time required for cleaning the silver with aluminum and with zinc indicates that in general there is little difference in the efficiency of these metals. In some instances aluminum and in others zinc cleaned the silver more rapidly. This apparent inconsistency is probably due to the fact that in some cases the metals became corroded or that the tarnish in some series of tests was slightly heavier than in others. Although the zinc cleaned very efficiently when first put into the solution, it soon became corroded and its efficiency thereby greatly reduced. For example, in three tests it was found that spoons having a uniform tarnish were not cleaned at the end of four, five, and four minutes, respectively, by a piece of zinc which had become corroded. After a new piece of zinc was substituted the spoons were cleaned in as many seconds. After the corroded zinc had been cleaned by immersing for about one minute in a solution of hydrochloric acid (one part HCl sp. gr. 1.2 to 10 parts of water) it cleaned practically as well as the new metal. Attempts were made to restore the efficiency to the corroded zinc by cleaning it with vinegar and also by rubbing it with various abrasives such as sand soap and emery paper, but without success.

EFFECT OF TEMPERATURE OF CLEANING SOLUTION.

A few experiments were made to determine whether this method of cleaning is efficient below boiling temperatures, since under household conditions it might be desirable to clean very large pieces of silver, which could be boiled only with difficulty, by immersing them in the hot cleaning solution contained in a tub or bucket. It was found, on an average, that at temperatures as low as 40° C. the silver was cleaned only after being immersed several minutes; at temperatures from 50 to 60° C. in about ten seconds; and at temperatures from 60 to 100° C. in about five seconds. At temperatures much below the boiling point, although the tarnish was removed, the cleaned silver had a somewhat dull appearance. From the results of these tests it is evident that the cleaning solution should be kept at the boiling point, since the tarnish is more quickly removed and the silver has a much brighter appearance than when cleaned in cooler solutions. In cases where it is not possible to boil the articles to be cleaned very hot cleaning solutions can be used with fairly satisfactory results.

RELATIVE MERITS OF THE ELECTROLYTIC AND POLISHING METHODS OF CLEANING SILVER.

From the theory of the cleaning process as formulated earlier in the paper it would appear that there is practically no loss in weight of the silver cleaned by the electrolytic method, since the tarnish of silver sulphid is merely reduced to metallic silver. In order to verify this, however, three sterling silver and three silver-plated spoons were weighed, tarnished and cleaned 50 times, and weighed after the final cleaning, zinc being used in a solution of 1 teaspoonful of sodium carbonate in 1 quart of water at the boiling temperature. During the 50 cleanings the three sterling silver spoons lost 0.0043, 0.0034, and 0.0034 grams and the three plated spoons lost 0.0026, 0.0019, and 0.0024 grams, or an average of 0.00006 grams in each cleaning. This loss is insignificant when compared with the loss in polishing with an abrasive silver polish which actually cuts away the tarnish, as was shown by the following test. One sterling silver and one silver-plated spoon were weighed, tarnished and cleaned six times by rubbing with a paste of finely powdered whiting and water, and weighed after the last cleaning. The spoons lost 0.0094 and 0.0087 grams, respectively, or an average of 0.0015 grams in each cleaning, about 25 times as much as by the electrolytic method. For a further comparison three sterling silver spoons were weighed, tarnished, and cleaned six times with a 5 per cent solution of potassium cyanid. By this method the spoons lost in weight 0.0135, 0.0129, and 0.0123 grams, respectively, an average of 0.0022 grams in each cleaning, a greater loss than by either of the other methods.

While the electrolytic method removes the tarnish effectively and with practically no loss of metal, it gives the articles cleaned a satin finish rather than the bright burnished appearance obtained when abrasive polishes are used. After the spoons used in these experiments had been cleaned a number of times by the electrolytic method it was found necessary to rub them with the paste of whiting and water to restore their original bright polish. In practice, therefore, it may be found desirable to use the electrolytic method as frequently as is necessary to remove the tarnish and to rub the silver with some good abrasive polish only as often as may be desirable to restore the burnished appearance.

A combination of the two methods is sometimes used by adding one or two teaspoonfuls of finely powdered whiting to each quart of the cleaning solution, and after removal the silver is allowed to dry without being rinsed. The film of whiting which adheres to it is then rubbed off with a soft cloth. This has the advantage of convenience, but the polish obtained is not so bright as when the two methods are used separately.

After one has tried both methods of cleaning silver it is obvious that much less labor is involved in the use of the electrolytic than the polishing method. As sodium carbonate in the form of washing soda and table salt are to be found in most homes, and since a small piece of aluminum or zinc can be purchased for a few cents, the cost of the two methods need not differ very much.

A HOUSEHOLD METHOD.

The details of a satisfactory method for household use are essentially as follows: An enamel or agate ware dish should be partly filled with a cleaning solution of 1 teaspoonful of either washing or baking soda and 1 teaspoonful of common table salt to each quart of water and placed directly on the stove to boil. A sheet of aluminum or clean zinc should then be dropped into the dish and the tarnished silver placed in contact with this metal. It is best that the silver be entirely covered with the cleaning solution and that the solution remain at the boiling temperature. As soon as the tarnish has been removed the silver should be removed, rinsed in clean water, and wiped with a soft cloth.

Aluminum corrodes quickly in the cleaning solution, so that aluminum dishes of any value for culinary purposes should never be used. Aluminum ware, which would otherwise be thrown away, or any inexpensive piece of the metal, will serve very satisfactorily for cleaning silver. Zinc may be used in place of aluminum, but it becomes corroded and inactive in a much shorter time. Unless it is possible to obtain a strong acid, such as muriatic acid, in which the activity of the zinc may be frequently renewed, it is inadvisable to try to employ this metal in the electrolytic method for cleaning silver.

SUMMARY.

Experiments have shown that the commercial devices for cleaning silver by the action of aluminum in solutions of soda are generally satisfactory. Zinc is less satisfactory than aluminum because it

becomes corroded and loses its efficiency. Sodium carbonate or bicarbonate, with or without the addition of sodium chlorid, are equally effective as the electrolyte of the solution, although to secure the best results the solution during cleaning should be kept at the boiling temperature. The electrolytic method cleans plated or sterling silverware without loss of metal, giving, however, a satin finish rather than a burnished appearance, and has the additional advantages of being clean and labor-saving.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 450

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER December 4, 1916

IMPROVEMENT OF GHIRKA SPRING WHEAT IN YIELD AND QUALITY.

By J. Allen Clark,

Scientific Assistant in Western Wheat Investigations, Office of Cereal Investigations.

CONTENTS.

	Page.
Introduction	1
History and description of Ghirka Spring wheat	2
Experiments	3
Comparative yields	3
Experiments—Continued.	
Summary of yields	8
Milling and baking quality	9
Improvement by selection	12
Conclusions	18

INTRODUCTION.

A demand for hardier and more drought-resistant wheats was created with the progress of settlement of the drier portions of the Great Plains area. In response to this demand, the United States Department of Agriculture began about 1898 to improve the wheat crop of that area by the introduction from eastern and southern Russia of varieties which were thought to possess hardiness and drought resistance. To determine the value of these varieties they were tested at agricultural experiment stations in different localities in the Great Plains area. The principal economic result of this work was the introduction of Kharkof winter wheat and Kubanka durum wheat.[1]

Some of the other varieties obtained were found of value for dry-land areas. Among them was the Ghirka Spring wheat, which was both productive and drought resistant, but comparatively low in milling value. Its improvement in yield and quality is the subject of the present paper.

[1] Carleton, M. A. Hard wheats winning their way. *In* U. S. Dept. Agr. Yearbook, 1914, p. 391–420, fig. 22–25, pl. 35–41. 1915.

60143°—16——1

HISTORY AND DESCRIPTION OF GHIRKA SPRING WHEAT.

The Ghirka Spring is the principal variety of beardless red spring wheat grown in Russia, particularly in southern Russia and the Volga River district. It forms a large part of the wheat exported from Russia.[1] This wheat has been introduced into this country several times. During the period from 1898 to 1904, inclusive, eight lots were obtained by the Office of Cereal Investigations of the United States Department of Agriculture. These lots are recorded as Cereal Investigations Nos. 1046, 1047, 1051, 1192, 1517, 1534, 2644, and 2646.

Other importations of this variety of wheat have been made by Russian immigrants. Joseph Dukart, who settled at New England, N. Dak., brought a 2-pound lot from Russia in 1905. From the

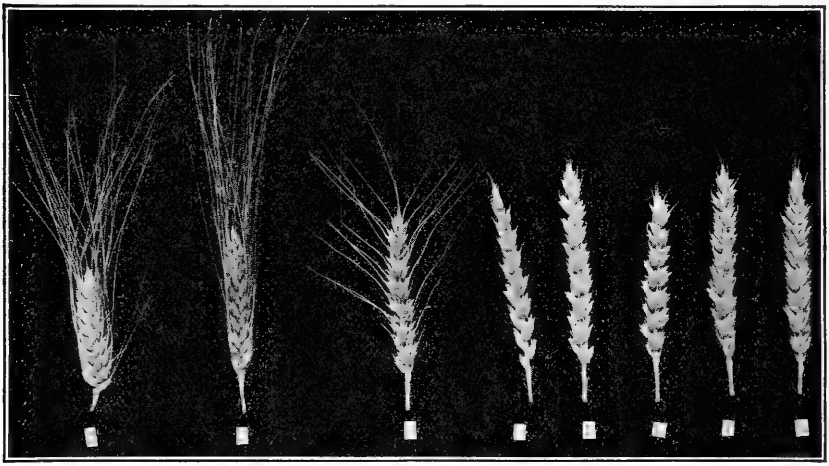

FIG. 1.—Heads of eight varieties of wheat grown at the Dickinson substation: (1) Kubanka durum; (2) Arnautka durum; (3) Preston; (4) Ghirka Spring; (5) Rysting Fife; (6) Marquis; (7) Crossbred Bluestem; and (8) Haynes Bluestem.

increase of this, several thousand acres are now grown annually in western North Dakota as "Russian" wheat. So far, however, the variety has never become commercially important in this country, though its acreage may be expected to increase.

The Ghirka Spring wheat has been placed in the Fife group of spring common wheat by most writers, as its characters are essentially the same as those of the varieties of that group (fig. 1). It differs from the Red Fife varieties in that it is earlier, has pubescent leaves, and the spike is a little more slender and distinctly more tapering at the tip. The kernel is slightly longer, a paler red, and a little softer.

[1] Carleton, M. A. Triticum vulgare. Ghirka. *In* U. S. Dept. Agr., Bur. Plant Indus. Bul. 66 (Seeds and plants imported), no. 6002. 1905.

There is a variety known as Ghirka Winter (C. I. No. 1438), which apparently differs from Ghirka Spring only in the winter habit and in having a shorter, stouter spike.

EXPERIMENTS.

This paper contains the results of experiments with only one of the department's introductions, Ghirka Spring (C. I. No. 1517) from Grodno Province in Russian Poland.

The experimental data are discussed under three separate topics, yield, quality, and improvement. The yield of the original unselected Ghirka Spring wheat is compared with that of three standard varieties at a series of seven stations during a period of seven years. The milling and baking qualities also are compared with those of the same three standard varieties grown at the Dickinson (N. Dak.) substation during three different years. Finally, the progress being made in improving both yield and quality by pure-line selection is shown.

COMPARATIVE YIELDS.

Ghirka Spring wheat has been tested in comparison with other domestic and foreign wheats at several agricultural experiment stations in the Great Plains area. Some of these tests have been conducted by the State stations, some by the United States Department of Agriculture, and some by the two in cooperation.

At the time this wheat was included in the varietal tests at the experiment stations in the northern part of the Great Plains, Bluestem and Fife were the standard wheats grown in that district, while durum wheat was becoming better known and its acreage increasing. The experiment stations were testing several varieties and strains of Fife and Bluestem wheats and many new varieties of durum wheat which were then being imported. The object of these varietal experiments was to determine which group of wheat was best adapted to each locality.

The work at the start was considered a local problem. The varietal tests at each station were practically independent of those at any other. As the work progressed, the best adapted groups and varieties became more and more evident at each testing station. When the results from all the stations in one part of this area are compared only group adaptations usually are shown. The best variety in each group has been not always the same at all stations. In some cases the variety leading at one station has not been grown at some of the other stations or, if grown, has been discarded if the yields were not satisfactory. For these reasons it is difficult to compare the results from individual varieties at a group of stations. It is possible, however, to present yields of Ghirka Spring wheat (C. I. No. 1517) from seven experiment stations in the northern Great Plains during the period of seven years from 1908 to 1914, inclusive. Yields of Kubanka durum wheat (C. I. No. 1440) and Haynes Bluestem wheat (C. I. No. 2874, Minn. No. 169) for the same years at the same stations are given for purposes of comparison.

It is desirable to compare the performance of Ghirka Spring with that of some other Fife wheat, but no one variety of Fife wheat other than Ghirka has been grown at all of the seven stations during this entire period. However, the Rysting Fife (C. I. No. 3022) has been grown at more stations during the period than any other variety of this group and is chosen for comparison. Yields of Glyndon Fife (C. I. No. 2873) have been substituted at the stations where the Rysting was not grown. The two varieties are very similar in appearance and are only different strains of Fife wheat.

The seven stations for which results [1] are presented are Moccasin, Mont.; Williston, Dickinson, and Edgeley, N. Dak.; and Brookings, Highmore, and Newell, S. Dak. The location and elevation of these stations are shown in figure 2. At all the stations except Edgeley, the work was conducted cooperatively by the United States Department of Agriculture and the State experiment stations. At Edgeley the tests were conducted entirely by the State, and the results given are quoted from the published annual reports of that substation for 1908 to 1913, inclusive. The results for 1914, not yet published, were kindly furnished by O. A. Thompson, superintendent of the Edgeley substation.

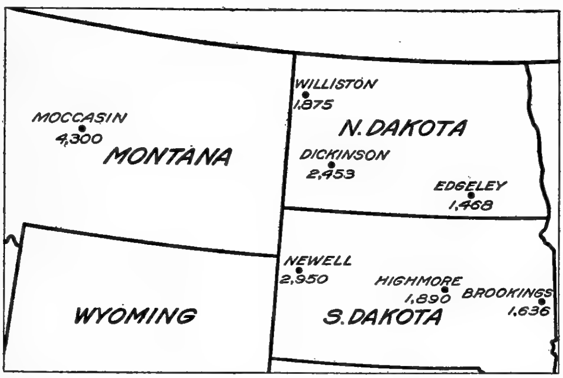

FIG. 2.—Sketch map of the northern Great Plains area, showing the location and elevation (in feet above sea level) of the seven experiment stations, results from which are discussed in this paper.

The annual and average yields of four varieties of wheat, Kubanka durum, Ghirka Spring, Rysting or Glyndon Fife, and Haynes Bluestem, grown at seven northern Great Plains experiment stations for the 7-year period from 1908 to 1914, inclusive,[2] are shown in Table I. The average yield of each variety for each station and also the average for all stations are shown graphically in figure 3.

[1] These data have been accumulated at the various stations by the following members of the scientific staff of the Office of Cereal Investigations: Manley Champlin (Brookings, S. Dak.); Charles H. Clark, J. A. Clark, and R. W. Smith (Dickinson, N. Dak.); J. D. Morrison (Highmore, S. Dak.); E. L. Adams and N. C. Donaldson (Moccasin, Mont.); Cecil Salmon and J. H. Martin (Newell, S. Dak.); and F. R. Babcock (Williston, N. Dak.).

[2] The manuscript of this bulletin was prepared in the spring of 1915, but publication has been unavoidably delayed. This bulletin includes experimental results only to the end of 1914.

The season of 1908 was a favorable one in regard to rainfall at all the stations here considered. Rather conflicting results were obtained with the Ghirka wheat at the different stations. The principal agreement in the tests was the outstanding yield of the Kubanka, surpassing the other varieties of wheat at Williston, Brookings, Highmore, and Newell, and equaling the yields of the Haynes and Ghirka Spring for first place at Moccasin and Dickinson, respectively. The Ghirka outyielded the other varieties at Edgeley, but, on the other hand, gave the lowest yield at Brookings, Highmore, and Newell. The exceptionally low yield of the Ghirka at Highmore and Brookings was due, in part at least, to rust. The average yield at the seven stations showed Kubanka first, Rysting-Glyndon second, Haynes third, and Ghirka fourth.

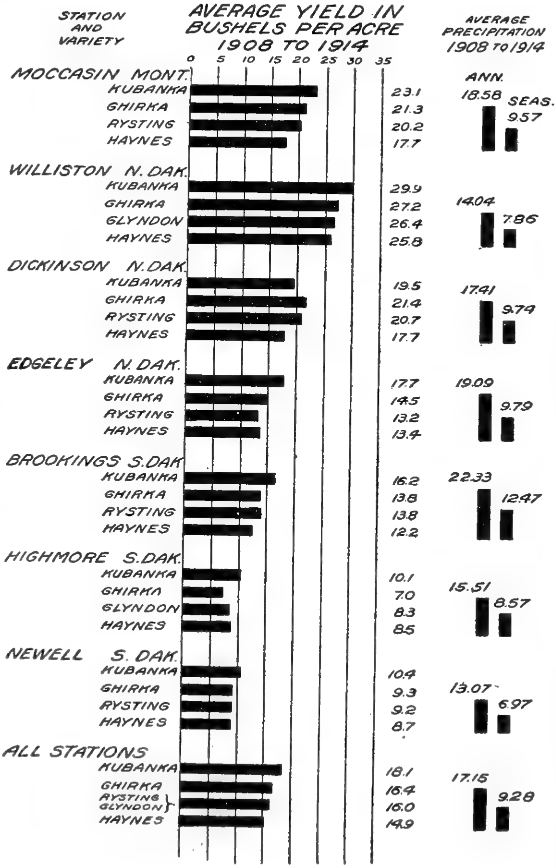

FIG. 3.—Diagram showing the average yields of four varieties of spring wheat and the annual and seasonal precipitation at seven experiment stations in the northern Great Plains area for the 7-year period from 1908 to 1914, inclusive.

The season of 1909 was unusually favorable at all the stations. Kubanka durum wheat gave the highest yields at Moccasin, Williston, Dickinson, Edgeley, and Newell. The Ghirka led at Brookings and Highmore, ranked second at Moccasin, third at Williston, and fourth at Dickinson, Edgeley, and Newell. Under the humid conditions of this year rust again caused a reduction in the yield of the Ghirka. For all stations the Kubanka ranked first, Ghirka second, Haynes third, and Rysting-Glyndon fourth.

The dry season of 1910 reduced the yields at all stations, and the results were entirely different from those obtained in previous years.

The Kubanka produced relatively low yields at all stations. This was caused by the sterility of the florets, probably induced by a combination of drought factors.[1] The Ghirka ranked first in yield at Moccasin, Williston, Dickinson, and Newell; second at Edgeley and Brookings; and fourth at Highmore. The results of this year showed that the Ghirka variety possessed real value as a drought-resistant wheat. For all stations the Ghirka ranked first, Rysting-Glyndon second, Haynes third, and Kubanka fourth.

TABLE I.—*Yields of the Ghirka Spring and three other varieties of wheat grown at seven experiment stations in the northern Great Plains area, 1908 to 1914, inclusive.*

Station and variety.	C. I. No.	Yield per acre (bushels).							
		1908	1909	1910	1911	1912	1913	1914	Average.
Moccasin, Mont.:									
Kubanka	1440	5.0	37.8	8.8	33.0	(a)	30.7	23.0	23.1
Ghirka	1517	3.3	34.2	13.2	25.2	(a)	29.0	23.0	21.3
Rysting	3022	2.5	29.0	13.0	27.0	(a)	26.7	23.0	20.2
Haynes	2874	[b]5.0	29.7	9.1	18.7	(a)	[c]22.8	[c]18.6	17.7
Williston, N. Dak.:									
Kubanka	1440	12.6	39.1	11.0	8.9	51.0	33.0	53.8	29.9
Ghirka	1517	[c]10.7	33.2	20.2	12.1	51.7	22.2	40.4	27.2
Glyndon	2873	9.8	31.2	13.9	8.0	44.7	28.2	49.2	26.4
Haynes	2874	10.5	34.3	8.8	[b]9.2	44.3	30.0	42.5	25.8
Dickinson, N. Dak.:									
Kubanka	1440	23.5	33.7	14.9	3.8	(a)	26.7	14.2	19.5
Ghirka	1517	23.5	28.9	28.6	9.5	(a)	26.6	11.3	21.4
Rysting	3022	22.3	33.0	20.7	7.7	(a)	28.1	12.4	20.7
Haynes	2874	21.4	30.0	13.1	8.6	(a)	24.8	8.3	17.7
Edgeley, N. Dak.:[d]									
Kubanka (Edgeley No. 6)		11.5	27.8	5.8	2.3	34.5	25.1	17.0	17.7
Ghirka (Edgeley No. 162)		12.4	19.7	7.9	2.0	20.1	30.6	9.0	14.5
Rysting (Edgeley No. 3)		10.1	20.3	6.2	1.6	21.7	25.2	7.0	13.2
Haynes (Edgeley No. 46)		7.9	19.9	9.0	2.0	23.5	27.8	4.0	13.4
Brookings, S. Dak.:									
Kubanka	1440	16.1	11.8	12.7	1.2	28.0	28.3	15.0	16.2
Ghirka	1517	8.8	17.7	16.2	.8	18.0	26.7	[c]8.7	13.8
Rysting	3022	14.9	15.5	16.9	3.0	16.8	20.0	9.2	13.8
Haynes	2874	11.6	16.9	15.7	2.8	15.8	20.2	2.5	12.2
Highmore, S. Dak.:									
Kubanka	1440	22.7	17.0	8.0	0	1.1	2.0	19.7	10.1
Ghirka	1517	4.8	17.7	6.2	0	2.4	6.5	11.3	7.0
Glyndon	2873	13.9	15.8	12.2	0	0	8.7	7.3	8.3
Haynes	2874	14.7	17.2	10.0	0	2.1	[b]7.7	7.5	8.5
Newell, S. Dak.:									
Kubanka	1440	24.9	21.4	5.3	0	0	15.6	[c]5.9	10.4
Ghirka	1517	16.2	11.7	12.8	0	1.9	16.3	[c]6.1	9.3
Rysting	3022	19.3	15.0	10.3	0	0	15.0	5.1	9.2
Haynes	2874	18.3	13.8	9.0	0	0	14.1	5.1	8.7
All stations:									
Kubanka	1440	16.6	26.9	9.5	7.0	22.9	23.1	21.9	18.1
Ghirka	1517	11.4	23.3	15.0	7.1	18.8	22.5	16.8	16.4
Rysting, Glyndon	3022, 2873	13.3	22.8	13.3	6.8	16.6	21.6	17.7	16.0
Haynes	2874	12.8	23.1	10.7	5.9	12.2	21.1	14.1	14.9

[a] Destroyed by hail in 1912.
[b] Yield of Haynes Bluestem (C. I. No. 3021, Minn. No. 51).
[c] Computed from the yields of the other varieties shown.
[d] Results from State substation; work not cooperative. Edgeley numbers and C. I. numbers represent the same original stocks.

A second successive dry season occurred in 1911 at all stations except Moccasin. There a plentiful rainfall caused the production of large yields. Under the favorable conditions at Moccasin, the

[1] Salmon, Cecil. Sterile florets in wheat and other cereals. *In* Jour. Amer. Soc. Agron., v. 6, no. 1, p. 24–30, 2 pl. 1914.

Kubanka led in yield, the Rysting ranking second and Ghirka third. At the other stations, under severe drought conditions, the yields decreased from the north to the south, no yields being obtained at Highmore and Newell. At Williston and Dickinson the Ghirka again yielded considerably better than the other wheats, but did not retain this advantage at the stations farther south. Early rust, as well as drought, reduced its yield at Brookings. For all stations, however, the Ghirka ranked first, Kubanka second, Rysting-Glyndon third, and Haynes fourth.

The annual and seasonal precipitation at each station for the seven years is given in Table II. The averages of these data are included also in figure 3, to aid in the interpretation of the yield data.

TABLE II.—*Annual and seasonal (April to July, inclusive) precipitation at seven experiment stations in three States of the northern Great Plains area, 1908 to 1914, inclusive.*

Station.	Precipitation (inches).							
	1908	1909	1910	1911	1912	1913	1914	Average.
Moccasin, Mont.:								
Annual	21.49	22.97	15.26	21.15	[a] 15.00	14.96	15.67	[b] 18.58
Seasonal	10.57	13.96	6.50	7.69	[a] 7.93	9.32	9.38	[b] 9.57
Williston, N. Dak.:								
Annual	13.49	11.74	10.28	13.69	16.33	14.28	18.47	14.04
Seasonal	7.00	9.05	5.48	5.70	10.20	5.63	11.98	7.86
Dickinson, N. Dak.:								
Annual	19.48	21.26	13.34	15.73	[a] 19.06	11.93	22.74	[b] 17.41
Seasonal	10.46	11.53	8.35	5.99	[a] 12.46	5.31	16.79	[b] 9.74
Edgeley, N. Dak.:								
Annual	17.07	15.14	12.21	15.47	21.84	19.82	18.05	17.09
Seasonal	9.24	10.55	4.01	6.87	15.59	9.06	13.23	9.79
Brookings, S. Dak.:								
Annual	32.34	22.34	12.78	24.95	23.18	16.58	24.15	22.33
Seasonal	19.60	10.64	6.74	10.62	14.95	10.69	14.09	12.47
Highmore, S. Dak.:								
Annual	22.37	18.03	11.15	15.87	11.16	12.46	17.52	15.51
Seasonal	12.50	8.52	6.93	5.41	6.00	8.59	11.98	8.57
Newell, S. Dak.:								
Annual	14.23	17.73	12.55	6.64	16.09	12.53	11.70	13.07
Seasonal	7.84	12.75	5.76	1.92	8.07	5.66	6.74	6.97
All stations:								
Annual	20.07	18.46	12.51	16.21	17.72	14.65	18.33	17.15
Seasonal	11.03	11.00	6.25	6.31	10.96	7.75	12.03	9.28

[a] These precipitation data are excluded from the average because the crop was destroyed by hail.
[b] Average for only 6 years, excluding 1912.

In 1912 the varieties at Moccasin and Dickinson were destroyed by hail and no yields were obtained, although very favorable conditions existed until the hail occurred. At Williston, under similar favorable conditions, unusually large yields were obtained. At Edgeley and Brookings the conditions were fair, while at Highmore and Newell the third successive droughty year occurred. The Ghirka slightly outyielded the Kubanka at Williston and also led the other varieties at Highmore and Newell. At the latter station it was the only variety of the four that produced grain, thus showing again its drought-resisting ability. Kubanka produced a yield a third greater than the other varieties at both Edgeley and Brookings, due largely to the greater rust resistance of the durum wheat. The rank in yield of the other three varieties at these two stations was reversed. For the five stations where results were obtained the Kubanka ranked first, Ghirka second, Rysting-Glyndon third, and Haynes fourth.

The favorable season of 1913 resulted in good yields at all stations except Highmore. The Kubanka led in yield at Moccasin, Williston, and Brookings, the Ghirka at Edgeley and Newell, the Rysting at Dickinson, and the Glyndon at Highmore. For all stations the Kubanka ranked first, Ghirka second, Rysting-Glyndon third, and Haynes fourth.

The season of 1914 was favorable at Moccasin and Williston, but drought, hail, and rust reduced the yields at the other stations. The yields have been computed for certain varieties which were not grown at three stations in 1914. The Haynes was discarded at Moccasin after 1912 and the Ghirka at Brookings after 1913. The Kubanka and Ghirka were unfortunately omitted, through error, from the test at Newell in 1914. The yields at Dickinson were damaged about two-thirds by hail. Rust reduced the yields at Edgeley, Brookings, and Highmore as much or more than drought.

The Kubanka produced the best yields at Williston, Edgeley, Brookings, and Highmore and equaled the yields of Ghirka and Rysting at Moccasin. The yield of Ghirka was relatively less at all stations except Moccasin than that usually obtained. For all stations the Kubanka ranked first, Rysting-Glyndon second, Ghirka third, and Haynes fourth.

SUMMARY OF YIELDS.

The averages for the seven years from 1908 to 1914, inclusive, covering a period of varying seasonal conditions, show a remarkable uniformity of results for the different varieties at each station. The Kubanka durum leads all varieties at all stations except Dickinson. Had the comparison included the results for 1907 at Dickinson the Kubanka would have outyielded the other varieties. A selection from Kubanka called Kubanka No. 8 (C. I. No. 4063) also outyielded the other varieties at Dickinson for the 5-year period from 1910 to 1914, inclusive.

The Ghirka has ranked second at Moccasin, Williston, Edgeley, and Newell, and tied with Rysting for second rank at Brookings. At Dickinson the Ghirka was first and at Highmore fourth.

The Rysting-Glyndon ranked third at Moccasin, Williston, Highmore, and Newell and tied at Brookings for second place. At Dickinson it ranked second and at Edgeley fourth.

The Haynes gave the lowest yields at Moccasin, Williston, Dickinson, Brookings, and Newell. It ranked third at Edgeley and second at Highmore.

The yield data presented are based on 182 actual determinations (crops destroyed by hail not considered). Yields have been computed in six other cases where the varieties were not sown and actual yields, therefore, were not obtained. This makes a total of 188 tests, or 47 tests for each of the four varieties. In three of these tests no yields of grain were obtained from all or from at least three of the varieties. In five other tests, either two or three of the varieties were equal in yield.

In 39 tests the four varieties can be definitely ranked. There are 24 possible combinations in which four varieties can rank. The varieties actually ranked in 15 of the possible 24 ways in the 39 tests. In annual yield, averaged for all stations, the varieties ranked in the same order only twice during the seven seasons. This shows conflicting annual results under varying seasonal conditions.

The varieties ranked first or equaled another variety for first rank, as follows: Kubanka 24 times, Ghirka 17 times, Rysting or Glyndon 6 times, and Haynes 2 times during 44 tests.

The average acre yield in 47 comparative tests at seven stations was 18.1 bushels for Kubanka, 16.4 bushels for Ghirka, 16 bushels for Rysting-Glyndon, and 14.9 bushels for Haynes. This shows a rather definite agreement of average results under varying seasonal conditions.

It is believed that the data presented fairly indicate what may be expected in yield from these four wheats in the northern Great Plains during a series of years.

The Ghirka variety has compared favorably with standard durum, Fife, and Bluestem varieties, yielding less than the durum but more than the Fife and Bluestem varieties on an average at seven stations during a 7-year period. While it is susceptible to rust in moist seasons, it has proved more drought resistant than the other wheats here studied, outyielding all others in the dry seasons.

MILLING AND BAKING QUALITY.

Quality as well as yield is an important consideration in determining the value of a variety. Quality of wheat is thought of in many different ways. To the farmer it means grade; to the miller and baker it is the ability of a wheat to produce a high percentage of flour and a loaf of large volume. Relatively few data have been gathered on the quality of the Ghirka wheat as compared with those on yield.

Hard spring common wheats grade as No. 1 Hard, No. 1 Northern, No. 2 Northern, etc. The Ghirka wheat when marketed has been included in the Northern grade. The somewhat soft kernel prevents its ever grading as No. 1 Hard. No extensive tests have been made of the crushing point of the Ghirka kernel compared with that of other varieties. A preliminary test, however, indicates the Ghirka to be about three-fourths as hard as the Haynes Bluestem and about one-half as hard as Kubanka durum wheat. This confirms the general opinion that Ghirka is a semi-hard rather than a hard wheat.

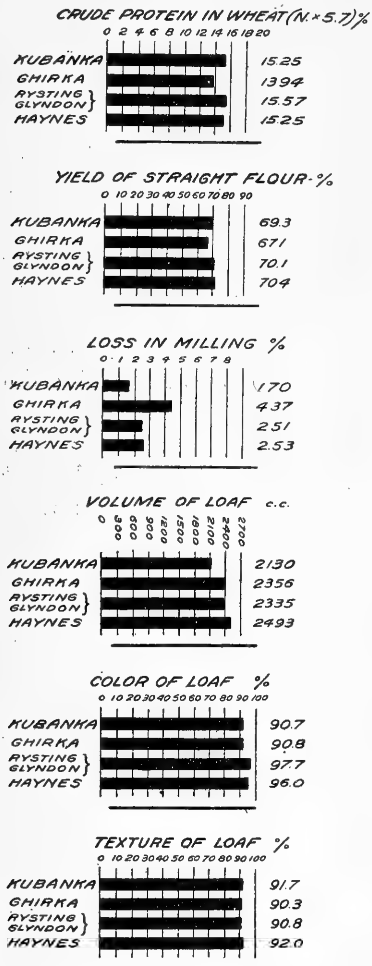

FIG. 4.—Diagram showing the average results of milling and baking tests of four varieties of wheat grown at the Dickinson substation during 1911, 1913, and 1914.

Many milling and baking tests have been made of Ghirka wheat grown at various stations, but the methods used by the investigators have varied. For several years the Office of Cereal Investigations and the North Dakota Agricultural Experiment Station have studied the milling and baking qualities of the principal wheats grown at the Dickinson substation. During three years, 1911, 1913, and 1914, the method used was the same. These data compare the milling and baking qualities of the Ghirka with those of the wheats already compared with it in regard to yield. The data for the Ghirka, Kubanka, and Haynes varieties are strictly comparable. The results from the Rysting in 1911 and 1913 have been combined with those from the Glyndon in 1914 to make the data somewhat comparable with those on yield. The annual and average results are given in Table III. In figure 4 only the average results are shown.

In 1911, data were obtained on the yield of straight flour and on the volume, color, and texture of the loaf. The Ghirka produced the lowest yield of flour and scored lowest in texture. The loaf volume was greater than that from the Rysting and the Kubanka, and the color of the loaf was better than that from the Kubanka. The Haynes gave the highest yield of straight flour, as well as the largest volume of loaf. The Rysting had the best color and texture of loaf.

In 1913, data on the crude-protein content of the kernel and on loss in milling were obtained for the first time. In that year the Ghirka was highest in loaf volume but lowest in crude-protein content and yield of straight flour, and it showed the greatest loss in milling. The low yield of flour and the loss in milling are especially pronounced. This is partly due to a peculiar fluffiness of the Ghirka flour. The Haynes gave the highest yield of straight flour and tied Kubanka for the highest score in texture of loaf. The Rysting had the highest percentage of crude protein in the wheat and the best color of loaf.

The data for 1914 show that the Ghirka is the poorest in crude-protein content and color and texture of loaf and shows the greatest loss in milling. The Haynes leads in crude-protein content and texture of loaf. The Glyndon yields more straight flour, produces the best volume of loaf, and ties with the Haynes in color of loaf.

The 3-year average of these data shows that the Ghirka variety has not compared favorably in quality with standard Bluestem, Fife, and durum wheats. It ranks relatively low in market grade, in crude protein, color and texture of loaf, and yield of straight flour, and has a large loss in milling. The volume of loaf is usually good, although averaging less than that of Bluestem.

TABLE III.—*Milling and baking tests of Ghirka and three other varieties of wheat grown at the Dickinson (N. Dak.) substation in 1911, 1913, and 1914.*[a]

Variety.	C. I. No.	1911	1913	1914	Average.
Crude protein (N × 5.7) in wheat (per cent):					
Kubanka	1440	....	15.50	14.99	15.25
Ghirka	1517	....	14.36	13.52	13.94
Rysting / Glyndon	[b] 3022 / [b] 2873	....	15.80	15.33	15.57
Haynes	2874	....	14.99	15.50	15.25
Yield of straight flour (per cent):					
Kubanka	1440	71.2	69.7	66.9	69.3
Ghirka	1517	68.7	65.3	67.3	67.1
Rysting / Glyndon	[b] 3022 / [b] 2873	71.2	70.6	68.4	70.1
Haynes	2874	73.5	71.2	66.6	70.4
Loss in milling (per cent):					
Kubanka	1440	....	2.57	.82	1.70
Ghirka	1517	....	5.94	2.80	4.37
Rysting / Glyndon	[b] 3022 / [b] 2873	....	3.22	1.80	2.51
Haynes	2874	....	2.68	2.37	2.53
Volume of loaf (cubic centimeters):					
Kubanka	1440	1,970	1,985	2,435	2,130
Ghirka	1517	2,150	2,270	2,648	2,356
Rysting / Glyndon	[b] 3022 / [b] 2873	2,060	2,000	2,945	2,335
Haynes	2874	2,320	2,260	2,900	2,493
Color of loaf (per cent):					
Kubanka	1440	83	93	96.0	90.7
Ghirka	1517	85	96	91.5	90.8
Rysting / Glyndon	[b] 3022 / [b] 2873	97	99	97.0	97.7
Haynes	2874	95	96	97.0	96.0
Texture of loaf (per cent):					
Kubanka	1440	86	94	95.0	91.7
Ghirka	1517	85	93	93.0	90.3
Rysting / Glyndon	[b] 3022 / [b] 2873	87	90	95.5	90.8
Haynes	2874	86	94	96.0	92.0

[a] The grain was milled and the bread baked at the North Dakota Agricultural Experiment Station.
[b] Results for 1911 and 1913 are from Rysting (C. I. No. 3022); for 1914, from Glyndon (C. I. No. 2873).

The Haynes has the highest average yield of flour, volume of loaf, and texture of loaf. The Rysting-Glyndon has the highest average crude-protein content and color of loaf. The Kubanka shows the smallest loss in milling.

The data given show that the Haynes is superior to the Ghirka in all of the six characters studied. The Rysting-Glyndon is superior in all characters except loaf volume, and the Kubanka is superior in all characters except volume and color of loaf.

IMPROVEMENT BY SELECTION.

The high-yielding and drought-resistant power of the Ghirka wheat was early recognized at the Dickinson substation. A further improvement in the yield and quality of the variety was sought through isolating a large number of pure lines and comparing them with the

FIG. 5.—Pure-line selections of Ghirka Spring wheat growing in eightieth-acre plats at the Dickinson substation in 1913.

original. This work was started in 1909, when about 300 heads were selected from a plat of the Ghirka wheat.[1] The kernels from these were sown in head rows in 1910. Yield data were obtained, and all the best, a large number of the medium, and some of the poorest were selected for sowing in 1911. Of these selections, 104 were sown in 17-foot rows for comparative yields, with the original Ghirka mass variety used as a check every third row. Eighty of the selections were sown also in rows of varying length to increase

[1] The experiments to improve the Ghirka Spring variety by pure-line selection were suggested by Supt. L. R. Waldron, of the Dickinson substation, who has maintained his interest in the work throughout the entire period. The original selections were made by Mr. Charles H. Clark, who was in charge of the cereal work at the Dickinson substation in 1909 and 1910. From 1911 to July 25, 1914, the writer was in direct charge of the cooperative cereal experiments at Dickinson. On the latter date he was succeeded by Mr. Ralph W. Smith, who continues in charge of the work as Scientific Assistant in Cereal Investigations.

the seed. Considerable variation was observed in the different pure lines, not only in respect to yield but also in the color and texture of the kernel, morphological characters of the plant, etc.

In 1912 the same 104 selections were sown in duplicated 17-foot rows with checks. About 20 were sown also in hundredth-acre plats. These tests were all destroyed by hail.

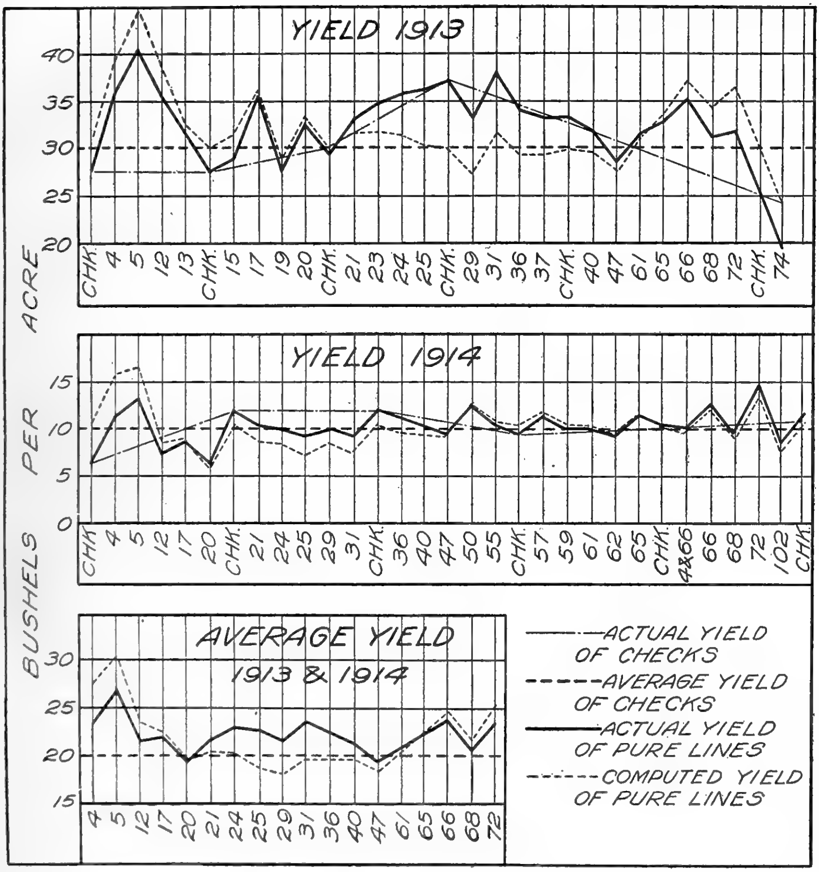

Fig. 6.—Diagram showing the annual and average actual and computed yields of Ghirka Spring wheat (C. I. No. 1517) used as a check and 30 pure lines selected therefrom, grown at the Dickinson substation in 1913 and 1914.

In 1913 the entire 104 selections were again sown in 17-foot rows from reserve stocks of seed. In addition, 86 of them were grown in 108-foot rows and 24 in plats (fig. 5) of one-eightieth acre. This series of tests gave considerable information on the behavior of these pure lines.

Samples of the grain from the 24 pure lines grown in field plats were used in milling and baking tests in cooperation with the North Dakota Agricultural Experiment Station.

In 1914 the work was continued. Besides the nursery work, 24 selections were again grown in field plats. Eighteen of these were the same as those grown in plats in 1913. The wheats were greatly damaged by hail which fell shortly before the crop was ripe. The plats were harvested, however, and yield data obtained. Milling and baking tests were also made on a number of the selections.

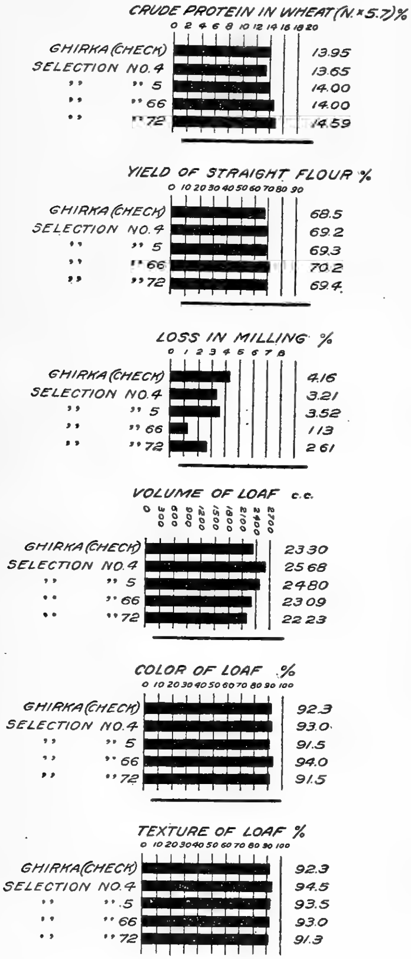

FIG. 7.—Diagram showing the average results of milling and baking tests of Ghirka Spring wheat (C. I. No. 1517) and four pure lines selected therefrom, grown at the Dickinson substation in 1913 and 1914.

The annual agronomic data for the pure lines grown in plats in 1913 and 1914 are given in Table IV, together with data from the check plats of the original Ghirka, C. I. No. 1517. In figure 6 are shown the results obtained in 1913 and 1914 and the average for the two years. The pure lines are arranged in the actual order of the sowings, and the actual and computed yields are shown separately. The actual yield of the check plats and the average for all checks are shown by different lines.

Improvement in the quality of Ghirka wheat is more important than increase in yield. It was hoped that a pure line would be found which had the combined characters necessary for good quality and high yield. A study of the milling and baking data obtained during the two years 1913 and 1914 on the highest yielding selections indicates that the desired result was obtained. These data are shown in Table V.

Figure 6 shows that in 1913 the Ghirka selections Nos. 4, 5, 17, 31, 66, and 72 were outstanding in regard to yield and that many others were better than the parent mass variety. The data for 1914 show that Nos. 4, 5, 50, 66, and 72 produced outstanding yields. An average of the yields of the pure lines grown both years shows Nos. 4, 5, 66, and 72 to be the best four selections when both actual and computed yields are considered, each showing an increase of more than

3 bushels over the parent variety. No definite conclusions can be drawn from the results of only two years, but the data indicate that improvement in yield is possible and that progress is being made. During the years covered by these data rust was not prevalent and no data were obtained on the rust-resisting ability of the different selections.

The average data for the four highest yielding pure lines and the parent mass variety are shown graphically in figure 7. The data given for the pure lines each year are an average of one milling and two bakings and for the parent variety are an average of these data from two plats, or an average of two millings and four bakings.

In 1913, Ghirka selections Nos. 4 and 66 exceeded the original Ghirka in crude-protein content and in yield of straight flour, gave a smaller loss in milling, and produced loaves of greater volume, which also scored higher in color and texture. This was an improvement in all of the characters here studied. Nos. 5 and 72 exceeded the original in some characters but failed to equal it in others.

In 1914, No. 4 gave the highest volume of loaf, but was low in crude protein and yield of straight flour, had a high loss in milling, and scored low in color. No. 66 scored low in volume of loaf and in texture, but otherwise exceeded the check. For the second year it showed an unusually low loss in milling.

Selection No. 5 led in crude protein and yield of straight flour, was superior to the original in volume and texture of loaf, and lost less in milling. Selection No. 72 was low in yield of flour and in volume, color, and texture of loaf. None of the four highest yielding pure lines exceeded the original variety in all characters in 1914.

The average for the two years shows that selection No. 4 was superior to the unselected Ghirka in all characters except crude-protein content and No. 66 in all characters except volume of loaf. No. 5 shows a decrease in crude protein and in color of loaf, while No. 72 shows a decrease in the volume, color, and texture of loaf. While none of the four best yielding selections has exceeded the mass variety in all of the characters studied, a gain in some of the characters offsets the loss in others, and the data thus far obtained indicate that at least the first three selections mentioned are superior in quality to the parent mass variety.

TABLE IV.—*Agronomic data for unselected Ghirka wheat, used as a check, and 30 pure lines selected therefrom, grown at the Dickinson (N. Dak.) substation in 1913 and 1914.*

Ghirka and selections.	C. I. No.	Date.		Planting to maturity.	Stand.		Height.	Yield per acre.				Weight per bushel.
		Headed, July—	Ripe, Aug.—		Plants per acre.	Estimated.		Actual.		Computed.		
								Grain.	Straw.	Grain.	Straw.	
Season of 1913:[1]				*Days.*	*Thousands.*	*Per ct.*	*In.*	*Bu.*	*Cwt.*	*Bu.*	*Cwt.*	*Lbs.*
Ghirka	1517	14	12	113	640	86	....	27.3	20.4	30.0	24.6	61
Selections—												
No. 4	4413	14	12	113	696	94	32.1	35.6	25.3	39.0	31.0	62
No. 5	4414	12	9	110	776	105	34.0	40.5	23.3	44.3	28.8	62.5
No. 12	4415	12	12	113	688	93	33.4	35.3	22.4	38.7	28.0	62.5
No. 13	......	10	10	111	844	114	34.2	31.3	19.6	32.3	25.2	61.5
Ghirka	1517	12	12	113	700	95	....	27.3	19.2	30.0	24.6	62.3
Selections—												
No. 15	4416	16	15	116	560	76	33.2	28.8	19.8	31.3	24.3	61.5
No. 17	4417	14	12	113	724	98	34.5	35.2	21.7	36.1	25.5	62.5
No. 19	......	12	12	113	860	116	34.3	27.7	20.2	28.9	22.9	61.5
No. 20	......	10	9	110	692	94	32.3	32.2	23.5	33.2	25.6	61
Ghirka	1517	12	12	113	700	95	....	29.5	23.5	30.0	24.6	62
Selections—												
No. 21	......	12	12	113	608	82	32.4	33.0	24.3	31.8	24.1	62
No. 23	4418	14	12	113	868	117	35.0	34.7	25.6	31.9	24.2	62.5
No. 24	4419	14	12	113	728	98	34.0	36.0	25.2	31.6	22.6	61.5
No. 25	4420	14	12	113	840	113	34.3	36.2	26.9	30.4	22.2	62
Ghirka	1517	12	12	113	680	92	....	37.2	30.1	30.0	24.6	62.5
Selections—												
No. 29	4421	10	9	110	860	116	32.3	33.2	25.7	27.3	21.5	61
No. 31	......	12	12	113	768	104	32.7	38.0	29.2	31.9	25.0	62
No. 36	......	12	12	113	820	111	32.3	34.1	28.0	29.3	24.5	62.5
No. 37	......	12	12	113	836	113	31.8	33.3	26.0	29.3	23.3	62
Ghirka	1517	12	12	113	648	88	....	33.3	26.8	30.0	24.6	62
Selections—												
No. 40	4422	12	12	113	768	104	31.7	32.0	23.2	29.7	21.2	62
No. 47	......	12	13	114	752	102	30.4	28.8	27.9	27.6	25.4	61
No. 61	......	12	9	110	688	93	34.3	31.7	26.7	31.4	24.1	62
No. 65	4424	14	9	110	896	121	33.4	33.0	25.9	33.8	23.4	61.5
No. 66	4425	12	12	113	828	112	31.6	35.2	25.9	37.3	23.1	61.5
No. 68	4426	10	10	111	792	107	....	31.3	22.0	34.5	19.7	60.5
No. 72	4427	11	12	113	720	97	33.9	32.0	25.6	36.6	22.9	62.5
Ghirka	1517	12	12	113	684	92	....	25.2	27.7	30.0	24.6	61
Selections—												
No. 74	......	12	12	113	524	71	34.2	19.3	17.6	24.0	22.8	61
Season of 1914:[2]												
Ghirka	1517	10	8	112	616	114	41.5	6.4	17.3	10.3	19.0	51
Selections—												
No. 4	4413	10	8	112	532	99	....	11.2	20.2	15.8	21.6	52.5
No. 5	4414	10	8	112	454	84	37.2	13.2	25.7	16.4	26.9	52.5
No. 12	4415	10	8	112	436	81	39.8	7.6	9.8	8.5	10.1	53
No. 17	4417	10	8	112	490	91	39.2	8.8	9.1	9.0	9.1	51.5
No. 20	......	10	8	112	460	85	36.7	6.4	24.0	5.9	23.6	49
Ghirka	1517	10	8	112	596	110	41.5	12.0	19.7	10.3	19.0	....
Selections—												
No. 21	......	12	8	112	460	85	39.9	10.4	20.6	8.9	20.1	53
No. 24	4419	10	8	112	464	86	39.9	10.0	23.8	8.6	23.2	51.5
No. 25	4420	10	8	112	440	82	41.1	9.2	20.4	7.2	20.2	52
No. 29	4421	8	8	112	456	85	39.2	10.0	19.0	8.6	18.9	49
No. 31	......	10	8	112	472	87	39.4	9.2	17.5	7.2	17.6	52
Ghirka	1517	10	8	112	644	119	39.8	12.0	18.7	10.3	19.0	52
Selections—												
No. 36	......	10	8	112	552	102	41.9	11.2	22.1	9.9	22.1	51.5
No. 40	4422	11	8	112	472	87	40.2	10.4	28.3	9.6	28.0	52
Selections—												
No. 47	......	10	8	112	644	119	38.1	9.6	15.4	9.2	15.0	51.5
No. 50	4423	9	8	112	636	118	40.3	12.8	25.0	12.7	24.1	52
No. 55	......	9	8	112	580	108	41.3	10.4	23.5	10.7	22.4	53.5
Ghirka	1517	10	8	112	604	112	40.4	9.6	20.2	10.3	19.0	51.5
Selections—												
No. 57	......	9	8	112	628	116	43.5	11.2	19.2	11.9	18.7	52
No. 59	......	11	8	112	532	99	38.8	10.0	27.6	10.4	27.9	51
No. 61	......	10	8	112	592	110	40.9	10.0	17.0	10.3	18.0	53
No. 62	......	10	8	112	516	96	40.7	9.2	22.3	9.4	24.5	50.5
No. 65	4424	10	8	112	544	101	37.1	11.2	20.2	11.2	23.1	51
Ghirka	1517	10	8	112	512	95	41.6	10.4	15.8	10.3	19.0	52
Selections—												
Nos. 4 and 66	......	9	8	112	528	98	40.1	10.0	21.8	9.8	24.5	52.5
No. 66	4425	9	8	112	584	108	42.6	12.4	27.1	12.0	28.8	52.5
No. 68	4426	10	8	112	524	97	39.2	9.6	18.2	9.2	18.2	51
No. 72	4427	10	8	112	496	92	....	14.4	29.8	13.6	28.2	51.5
No. 102	......	14	8	112	664	123	....	8.4	24.7	7.8	22.3	49
Ghirka	1517	11	8	112	596	110	42.4	11.2	22.1	10.3	19.0	52.5

[1] Sown Apr. 21, emerged May 10, harvested Aug. 15, 1913.
[2] Sown Apr. 18, emerged May 2, harvested Aug. 10, 1914.

Table V.—*Milling and baking data for Ghirka wheat, used as a check, and 25 pure lines selected therefrom, grown at the Dickinson (N. Dak.) substation in 1913 and 1914.*

Plat No.	Variety.	C. I. No.	Crude protein in wheat (N× 5.7).	Yield of flour.	Loss in milling.	Loaf.		
						Volume.	Color.	Texture.
	Season of 1913:							
	Selections—		*Per ct.*	*Per ct.*	*Per ct.*	*C. c.*	*Per ct.*	*Per ct.*
2	No. 4	4413	14.36	71.2	3.35	2,450	96	94
3	No. 5	4414	13.45	69.6	.5.65	2,300	94	93
4	No. 12	4415	14.42	68.7	4.75	2,320	92	94
5	No. 13		14.99	67.1	5.78	2,130	84	88
7	No. 15	4416	15.28	69.9	7.39	1,860	92	88
8	No. 17	4417	13.97	68.5	5.14	2,200	99	92
9	No. 19		15.28	69.1	4.50	2,265	96	93
10	No. 20		16.07	68.9	5.10	1,885	90	90
12	No. 21		14.82	70.5	2.85	2,155	94	92
13	No. 23	4418	14.36	69.8	4.50	2,150	89	90
14	No. 24	4419	14.54	67.2	5.98	2,350	89	94
15	No. 25	4420	15.16	70.3	4.01	2,065	89	90
17	No. 29	4421	15.62	67.5	7.10	1,790	94	86
18	No. 31		15.28	70.1	4.17	1,985	90	92
19	No. 36		15.16	69.8	4.32	2,030	91	90
20	No. 37		14.54	70.4	4.57	1,895	86	90
22	No. 40	4422	14.54	72.0	3.10	2,120	95	93.5
23	No. 47		14.88	70.7	4.77	2,110	96	93
24	No. 61		14.71	69.2	5.73	2,080	93	93
25	No. 65	4424	14.48	68.9	5.17	2,050	94	94
26	No. 66	4425	14.76	72.4	1.46	2,097	95	93.5
27	No. 68	4426	15.50	67.2	7.68	1,825	89	85
28	No. 72	4427	14.99	72.2	3.49	1,975	92	92
30	No. 74		14.71	71.7	4.21	1,895	90	89
21, 29	Ghirka	1517	13.88	69.6	5.51	2,011	93	91.5
	Season of 1914:							
	Selections—							
2	No. 4	4413	12.94	67.2	3.06	2,685	90	95
3	No. 5	4414	14.54	69.0	1.39	2,660	89	94
9	No. 24	4419	13.22	66.9	2.67	2,675	94	92
11	No. 29	4421	13.97	66.0	2.06	2,590	90	92
15	No. 40	4422	14.36	65.7	2.60	2,320	93	89
17	No. 50	4423	14.71	68.0	1.80	2,405	93	90
27	No. 66	4425	14.36	67.9	.80	2,520	93	92.5
29	No. 72	4427	14.19	66.5	1.73	2,470	91	90.5
13, 25	Ghirka	1517	14.02	67.3	2.80	2,648	91.5	93

A comparison of these three pure lines with standard varieties will serve to show their relative values. Five such varieties have been grown and a comparison is made of their annual and average yields per acre, percentages of straight flour, and volumes of loaf in Table VI. While the data on yield are not strictly comparable, owing to the difference noted in the size of plats, they show that the selections possess the ability to produce comparatively high yields. In percentage of straight flour the average shows that selection No. 66 exceeds any of the other varieties studied, while selections Nos. 5 and 4 exceed the Haynes, Marquis, and Red Fife. In volume of loaf the Haynes slightly exceeds selection No. 4, which, in turn, is superior to the Red Fife, Preston, Marquis, and Kubanka, while selection No. 5 is superior to the Preston, Marquis, and Kubanka, and selection No. 66 is superior to the Kubanka.

These selections and several others are being further tested to determine more accurately their true value before any are distributed.

TABLE VI.—*Yields of grain and of flour and volumes of loaf obtained from three pure-line selections of Ghirka and five standard varieties of hard spring wheat grown at the Dickinson (N. Dak.) substation in 1913 and 1914.*

[The varieties are arranged in the order of their average yields.]

Variety.	C. I. No.	1913	1914	Average.
Yield per acre (bushels):				
Ghirka No. 5	4414	a 40.5	b 13.2	26.9
Ghirka No. 66	4425	a 35.2	b 12.4	23.8
Ghirka No. 4	4413	a 35.7	b 11.2	23.5
Kubanka	1440	c 31.2	d 14.2	22.7
Red Fife	3329	c 28.3	d 10.2	19.3
Preston	3081	c 25.6	d 12.9	19.3
Marquis	3641	c 24.0	d 14.0	19.0
Haynes	2874	c 24.8	d 8.3	16.6
Yield of straight flour (per cent):				
Ghirka No. 66	4425	72.4	67.9	70.2
Kubanka	1440	71.8	66.9	69.4
Preston	3081	70.7	68.1	69.4
Ghirka No. 5	4414	69.6	69.0	69.3
Ghirka No. 4	4413	71.2	67.2	69.2
Haynes	2874	71.2	66.6	68.9
Marquis	3641	69.2	63.8	66.5
Red Fife	3329	71.8	60.0	65.9
Volume of loaf (cubic centimeters):				
Haynes	2874	2,260	2,900	2,580
Ghirka No. 4	4413	2,450	2,685	2,568
Red Fife	3329	2,220	2,775	2,498
Ghirka No. 5	4414	2,300	2,660	2,480
Preston	3081	2,170	2,785	2,478
Marquis	3641	2,250	2,475	2,363
Ghirka No. 66	4425	2,097	2,520	2,309
Kubanka	1440	1,985	2,435	2,210

a Plats one-eightieth of an acre.
b Plats one forty-eighth of an acre.
c Plats one-tenth of an acre.
d Plats one forty-eighth of an acre, replicated four times.

It is possible that a mixture of two or three of the best selections may result in a further improvement in yield or quality. A preliminary test to determine this, combining selections Nos. 4 and 66, is already under way. Crosses have been made between these best pure lines and other varieties of hard spring common wheat, and promising selections of the progeny of the second and fourth generations are now in existence. From these a still further improvement in quality and in rust resistance is expected, while retaining the high-yielding and drought-resistant qualities of the Ghirka wheat.

CONCLUSIONS.

Ghirka Spring wheat, a variety of commercial importance in Russia, has proved adapted to the northern part of the Great Plains area of the United States. The variety is susceptible to rust in moist seasons and in humid areas, but it has proved to be a valuable drought-resistant wheat.

Tests at seven experiment stations in the northern Plains area, covering a period of seven years, have shown that on an average the Ghirka Spring has yielded more than the Rysting Fife and Haynes Bluestem common wheats, but less than the Kubanka durum wheat. The quality of the Ghirka, however, is inferior to that of these standard wheats.

Experiments are being made at the Dickinson (N. Dak.) substation to improve both the yield and the quality of the Ghirka wheat by isolating superior pure lines. Many pure lines have been tested, and among them selections Nos. 4, 5, and 66 have thus far proved superior to the others and to the original mass variety in both yield and quality. They also compare favorably with the standard spring wheats of the Great Plains area in quality as well as in yield. The selections are also proving valuable material for crossing with varieties possessing greater rust resistance and high quality of grain.

From the data given it is shown that improvement in yield and quality is possible from pure-line selection and that good results are being obtained.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 426

Contribution from the Forest Service
HENRY S. GRAVES, Forester

Washington, D. C. PROFESSIONAL PAPER December 30, 1916

SUGAR PINE

By

LOUIS T. LARSEN, Forest Examiner, and T. D. WOODBURY, Assistant District Forester

CONTENTS

	Page
Importance of Sugar Pine	1
Geographical and Commercial Range	2
Habit and Root System	3
Bark, Leaves, Flowers, and Seed	3
Size and Longevity	4
Susceptibility to Injury and Disease	4
Silvical Requirements	7
Reproduction	8
Forest Types	9
The Wood	10
Logging	12
Milling	13
Values and Grades of Lumber	16
Markets	20
Uses	20
Stumpage Prices	23
Growth and Yield	24
Management	20
Management of Private Timberlands	35
Appendix	37

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 427

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 6, 1917

THE POTATO TUBER MOTH

By

J. E. GRAF, Entomological Assistant, Truck Crop and Stored Product Insect Investigations

CONTENTS

	Page
Historical	1
Distribution	2
Possible Origin	3
Nature of Injury	4
Economic Importance	6
Classification and Synonymy	9
Description	9
Food Plants	14
Life History and Habits	15
Natural Enemies and Checks	32
Artificial Control	48
Summary	51
Bibliography	52

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 428

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER January 9, 1917

MEDICAGO FALCATA
A YELLOW-FLOWERED ALFALFA

By

R. A. OAKLEY, Agronomist, and SAMUEL GARVER
Scientific Assistant, Office of Forage-Crop
Investigations

CONTENTS

	Page
Introduction	1
Introduction of Medicago falcata into the United States	2
Natural Distribution	5
Climatic and Soil Requirements	7
Botanical History	8
Botanical Description and Relationship	13
Agricultural History	33
Agronomic Characteristics	35
Cultural Investigations	51
Possibilities in Selection and Hybridization	56
Present Agronomic Status	61
Summary	63
Literature Cited	67

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 429

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER February 28, 1917

LIFE HISTORY OF THE CODLING MOTH IN THE PECOS VALLEY NEW MEXICO

By

A. L. QUAINTANCE, Entomologist in Charge of Deciduous Fruit Insect Investigations, and E. W. GEYER, Scientific Assistant

CONTENTS

	Page
Introduction	1
Definition of Terms Used	2
Seasonal-History Studies of 1912	3
The Spring Brood	3
The First Generation	6
The Second Generation	13
The Third Generation	25
Seasonal History of the Codling Moth During 1912	31
Band-Record Larvæ of 1912	32
Seasonal-History Studies of 1913	34
Source of Rearing Material	34
Method of Procedure	35
Seasonal-History Studies of 1913—Con.	
The Spring Brood	36
The First Generation	42
Egg Deposition by Individual Moths	50
The Second Generation	56
The Third Generation	68
The Fourth Generation	78
Miscellaneous Emergence of Moths	79
Band Records of 1913	80
Seasonal History of the Codling Moth During 1913	87
Summary	87

WASHINGTON
GOVERNMENT PRINTING OFFICE
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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 430

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ October 28, 1916

CEREAL EXPERIMENTS ON THE CHEYENNE EXPERIMENT FARM ARCHER, WYO.

By

JENKIN W. JONES, Scientific Assistant
Office of Cereal Investigations

[In cooperation with the Wyoming State Board of Farm Commissioners]

CONTENTS

	Page
Introduction	1
Description of the District	2
Cheyenne Experiment Farm	8
Experiments with Wheat	12
Experiments with Emmer and Spelt	25
Experiments with Oats	26
Experiments with Barley	30
Experiments with Flax	33
Experiments with Minor Grain Crops	36
Summary	38

WASHINGTON
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UNITED STATES DEPARTMENT OF AGRICULTURE

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L. O. HOWARD, Chief

Washington, D. C. | PROFESSIONAL PAPER | February 9, 1917

SACBROOD

By

G. F. WHITE
Expert, Engaged in the Investigation of Bee Diseases

CONTENTS

	Page
Introduction	1
Historical Account	2
Name of the Disease	4
Appearance of Healthy Brood at the Age at Which it Dies of Sacbrood	6
Symptoms of Sacbrood	10
Cause of Sacbrood	24
Weakening Effect of Sacbrood Upon a Colony	30
Amount of Virus Required to Produce the Disease, and the Rapidity of its Increase	31
Methods Used in Making Experimental Inoculations	32
Means for the Destruction of the Virus of Sacbrood	34
Heating Required to Destroy Sacbrood Virus When Suspended in Water	34
Heating Required to Destroy Sacbrood Virus When Suspended in Glycerine	35
Heating Required to Destroy Sacbrood Virus When Suspended in Honey	36
Resistance of Sacbrood Virus to Drying at Room Temperature	37
Resistance of Sacbrood Virus to Direct Sunlight When Dry	38
Resistance of Sacbrood Virus to Direct Sunlight When Suspended in Water	39
Resistance of Sacbrood Virus to Direct Sunlight When Suspended in Honey	40
Length of Time that Sacbrood Virus Remains Virulent in Honey	40
Resistance of Sacbrood Virus to the Presence of Fermentative Processes	41
Resistance of Sacbrood Virus to Fermentation in Diluted Honey at Outdoor Temperature	42
Resistance of Sacbrood Virus to the Presence of Putrefactive Processes	43
Resistance of Sacbrood Virus to Carbolic Acid	44
Modes of Transmission of Sacbrood	46
Diagnosis of Sacbrood	48
Prognosis	49
Relation of These Studies to the Treatment of Sacbrood	50
Summary and Conclusions	52
Literature Cited	53

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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BULLETIN No. 433

Contribution from the Bureau of Animal Industry
A. D. MELVIN, Chief

Washington, D. C. PROFESSIONAL PAPER February 15, 1917

CHANGES IN FRESH BEEF DURING COLD STORAGE ABOVE FREEZING

By

RALPH HOAGLAND, CHARLES N. McBRYDE, and WILMER C. POWICK, of the Biochemic Division

CONTENTS

	Page
Hygienic Value of Cold Storage	1
Commercial Practices in the Cold Storage of Fresh Beef	2
Previous Investigations on Cold Storage of Meats	5
Purpose and Plan of Present Investigation	7
Autolysis Experiments	8
Cold-Storage Experiments with Fresh Beef	29
Effects of Cold Storage upon the Nutritive Value of the Beef	95
Factors Affecting the Time that Fresh Beef can be Stored at Temperatures Above Freezing	97
General Summary	99
References to Literature	100

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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BULLETIN No. 440

Contribution from the Forest Service
HENRY S. GRAVES, Forester

Washington, D. C. PROFESSIONAL PAPER March 8, 1917

LUMBERING IN THE SUGAR AND YELLOW PINE REGION OF CALIFORNIA

By

SWIFT BERRY, Forest Examiner

CONTENTS

		Page
Part I.	Introduction	1
	The Region	1
	The Forest	2
	Types of Operations	4
	Labor	5
	Camps	8
	Factors Affecting the Cut	10
Part II.	Logging	13
	Preparing Logs for Transport	13
	From Stump to Yard	18
	From Yard to Landing	34
	From Landing to Mill	41
	Woods Supervision	64
Part III.	Manufacture	65
	Mill pond	65
	Sawmills	67
	Sawmill Lumber Yards	80
	Transportation to Common Carriers	86
Part IV.	General Cost Factors	92
	Overhead Charges	92
	Depreciation	95
	Summary of the Costs of Typical Operations	96

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 445

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ February 10, 1917

THE NAVEL ORANGE OF BAHIA WITH NOTES ON SOME LITTLE-KNOWN BRAZILIAN FRUITS

By

P. H. DORSETT, A. D. SHAMEL, and WILSON POPENOE
Agricultural Explorers, Office of Foreign Seed and Plant Introduction

CONTENTS

	Page
Introduction	1
Origin and History of the Navel Orange of Bahia	1
Introduction of the Washington Navel Orange of Bahia into the United States	4
Culture of the Navel Orange in Bahia	7
Citrus Fruits of Bahia Other than the Navel Orange	15
Citrus Fruits of the Region around Rio de Janeiro	16
Miscellaneous Fruits Grown at Bahia	17
Some Interesting Fruits of Rio de Janeiro and Vicinity	25
Fruits of the Highlands and Semiarid Regions of Minas Geraes and Bahia	31

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 448

Contribution from the Bureau of Chemistry
CARL L. ALSBERG, Chief

Washington, D. C. PROFESSIONAL PAPER February 15, 1917

SEPARATION AND IDENTIFICATION OF FOOD-COLORING SUBSTANCES

By

W. E. MATHEWSON, Assistant Chemist

CONTENTS

	Page
Introduction	1
General Statements Concerning Reagents Used in Color Analysis	2
Preliminary Treatment of Food Products	4
Separation and Purification of Coloring Substances	8
Identification of Coloring Substances	35

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1917

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